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REPORT UPON ENGINEERING EDUCATION.[1]

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IT is now nearly a decade since the inception of the University of Chicago, and since I wrote an earnest letter urging the establishment of an engineering school of high order in connection with it. The efforts to establish such a school have thus far been without success.

In 1891, while making engineering examinations in Europe, I undertook to gather some information and opinions on the subject. Illness and pressing business prevented any further active efforts in this direction until the last summer and fall, when it was my good fortune to spend six or seven months on an extended professional tour for the examination of various kinds of engineering works from the north of Ireland and Scotland to Russia and Hungary. I made the best possible use of the opportunity to examine engineering schools, to confer with their professors, to talk with engineers, to obtain descriptive catalogues and the calendars of the institutions, to ascertain the different methods of engineering education in the various countries visited, and to observe, so far as I was able, the effect upon the engineering profession and its works of thorough education and the lack of it.

[1] Prepared with reference to a proposed School of Engineering at the University of Chicago.

In addition to these personal observations, inquiries and conferences, I have conducted during seven years an extensive correspondence. As chairman of the General Committee of the Engineering Congress held in Chicago in 1893, I had charge for two years of a correspondence with engineers in forty-three different countries, which led to a valuable personal or correspondence acquaintance with my profession, and this has enabled me to gain easily much information which otherwise it might have been difficult to obtain. During the last seven months I have taken up this correspondence again in order to obtain some information and views from countries which I was not able to visit.

It would be manifestly impracticable to do more than to give the very briefest digest of this mass of information. I propose to give, cursorily, the present methods of teaching engineering, taking the schools in fairly good geographical order, beginning in the north of Ireland, and going as far east on the Continent as the methods have come under my notice. In order to make comparisons with schools in the United States, I shall select two from among the many in our country for a brief review of methods there. In reference to this selection of American schools I would not have it understood that it is made because I consider these schools superior to others, but because they are fair examples of the highest order of schools in our country.

To endeavor to draw conclusions as to the best methods would require more courage, and possibly more assurance, than would be expected of a layman, particularly since the doctors in engineering differ radically among themselves, not only in regard to details, but even regarding the general character and extent of the education.

I cannot safely do more than give my recommendations as to the kind and character of school we ought to have to harmonize with the principle upon which the university was based by its founder, which, I believe, was to enable our young people to obtain in the United States the advanced education which they might need, or might desire, without being obliged to go across the ocean to find it.

With this cardinal purpose in mind, the drift of the remainder of this report will be understood, appreciated, and assented to by all.

With this brief introduction we are now ready to describe the institutions in the various countries.

IRELAND.

Three colleges, affiliated with the Royal University of Ireland, have a School of Engineering — Belfast, Galway, and Cork. The degree of Bachelor of Engineering is given, and later, not less than a year, the degree of Master of Engineering. Candidates for Bachelor of Engineering must pass five examinations, requiring four years of study, viz., the matriculation, first university, first professional, second professional, and the degree examination. The first, or matriculation, examination requires a previous preparatory course in, or knowledge of, Latin and either Greek or one of eight other languages, English language and literature, elementary mathematics, and natural philosophy. The first two examinations are identical for all students of the university, so that the beginning of the second year is the point of divergence for the professional course. There are three of these professional examinations, each in four subjects, embracing, first, mathematics, experimental physics, systematic chemistry, drawing, and descriptive architecture; second, mathematics, mathematical physics, practical chemistry, and practical engineering; and third, mathematical physics, geology including physical geography, civil engineering, and drawing. The course for the degree of Master of Engineering requires applied natural philosophy and engineering.

It will be seen from the above that engineering *per se* holds no prominent position in the course; the fact that there is only one professor of civil engineering at Belfast is confirmation of the statement.

The School of Engineering at Cork is supplied with an Adge cement-testing apparatus, a Thurston testing machine, and a thirty-ton Wicksteed testing machine.

The principle of the course seems to be to give the student a good general education and sufficient technical knowledge to make him useful as an apprentice in some prominent practicing civil engineer's office or mechanical engineering works, to which he is articled on graduation, if he is fortunate enough to find an employer.

This principle and method are illustrated in the excellent School of Engineering (Trinity College) at the University of Dublin. Here the student, in order to obtain a "License in Engineering," must have not only completed his course in the engineering school, requiring three years, but also the first two years in the course in arts. To obtain the degree of B.E. he must have not only completed the engi-

neering course, but also graduated in arts, which requires a good knowledge of Latin and Greek. The degree of M.E. requires actual practice for three years upon engineering works. An examination of this school and its methods, of which I was informed fully by one of the leading professors, and a study of the regulations and course of study led me to believe that a high order of theoretical and practical education must result. The views of the professor referred to above may be understood from the following brief memorandum from my notebook: "They do not give an engineering degree or any university degree without a course in arts, the plan being to give first a liberal education and then a professional education, considering it wisest to give the young man for his life work the breadth and scope and intellectual grasp that can only come from a liberal education with its mental training."

The Royal School of Science for Ireland is also located in Dublin, and is under the department of science and art, South Kensington, which has undertaken the management of several technical and industrial schools in Great Britain.

Scotland.

At Dundee is *University College*, a part of St. Andrew's University. It has a department of engineering, well equipped with modern appliances and everything required for research and experiment. Three years of study in engineering and science are required for the degree of B.Sc. in engineering, which is given by the university. A thorough course of study, with apparatus for experiments and illustrations, a steam engine of 75 H. P., a gas engine of 10 H. P., a high-pressure tubular boiler, various testing machines (one testing up to fifty tons) and a number of appliances for experimental work, with dynamos, electric machines, and an extensive apparatus for electrical laboratory work, all place this excellent school in a high rank among the engineering schools of Great Britain. One advantage, which would not appear if the engineering school alone is spoken of, is the teaching of allied sciences in the Dundee college — chemistry, mathematics, and natural philosophy, including mechanics, kinetics, hydrostatics, optics, thermodynamics, magnetism, and electricity. Electrical engineering is taught in connection with this science department. Instruction in all these physical sciences of the university is fully supplemented by well-equipped laboratories.

The *University of Edinburgh* is giving more attention than formerly to engineering education. Seven years ago, when I made my first examination into this subject in Europe, the beginnings of a "plant" were being installed, boiler, engine, etc. The engineering department is now well advanced in these facilities. It is, however, uphill work to obtain the costly apparatus required to keep abreast of the times in appliances used in other countries, on account of the great difficulty in obtaining the means to furnish adequately the department with what it needs; in fact, this is the keenly felt want almost anywhere in Great Britain, as it is in the United States. On the Continent it is different, for the State takes a paternal and active, and generally controlling, interest in education, particularly technical and industrial education, as we shall see further on.

There are four faculties in the Edinburgh University — arts, law, medicine, and divinity. The science features are included in arts, and there is, of course, the department of engineering, its object being the practical application of the scientific studies to the various branches of engineering. The course is two years. The university confers the degrees of Bachelor and Doctor of Science.

The *University of Glasgow* will celebrate its four hundred and fiftieth anniversary in 1900, for in 1450 it was founded by Pope Nicholas V. In 1840 Queen Victoria founded a special chair of civil engineering and mechanics. The engineers of whose lives and usefulness Samuel Smiles has told the world had already left their impress. Telford, Smeaton, Stephenson, Brunel, and many other remarkable men had founded a new profession, which before the end of the nineteenth century was destined to take rank with the learned professions. There are four courses to obtain the degree of B.Sc.: civil engineering, chemical and mining engineering, mechanical and electrical engineering, and naval architecture and marine engineering. The courses of study are arranged accordingly, though as published by Professor Rankine, in 1865, they are not intended in any way to compete "with the offices of civil engineers," where the young men were taught practical engineering.

There is now a chair of naval architecture, the occupant of it being the distinguished naval architect, Professor J. H. Biles.

The University of Glasgow proposes to the student of engineering a complete general or liberal education as a necessary feature; evidently for

the purpose of sending out strong, able men with an education, broad not only in science, but in humanities as well. Its latest requirements for obtaining the degree of Bachelor of Science in Engineering, that of the present year, 1897–98, compel a successful preliminary examination in arts, — English, Latin or Greek, mathematics, and one of the following modern languages, French, German or Italian. The details of the required knowledge in each show that no smattering of any of them will avail the candidate; he must have a thorough as well as extensive knowledge of each subject, and in mathematics the student must pass in dynamics as well, including kinematics, kinetics, statics, and hydrostatics.

Of course an actually earned degree in arts and sciences in any of the universities of the United Kingdom is equivalent to a successful examination.

I have given special prominence to Glasgow University, as it is one of the four that demand an advanced preliminary education in liberal studies, and because from personal conference I am sure it has as high an aim and as wide a scope in its education of engineers as can be found anywhere, although it may content itself with less practical teaching of engineering, in laboratory and workshops, than we will find elsewhere as we go on with the description of the various schools of Europe.

It is evident, however, that with such requirements for admission to its engineering department, and with at least three years required in that department to obtain the degree of Bachelor of Science in Engineering, the most complete and thorough education is certain to result.

England.

The Durham College of Science, at Newcastle-upon-Tyne, is one of the most progressive, earnest, and practical schools in Europe. It could hardly be otherwise, located as it is in that great hive of industry, where, from the great Armstrong works down to the minor manufactories of various kinds, almost every branch of constructive engineering work is carried on, a section of country growing with great rapidity in commerce, industry, and population.

The college forms an important part of the University of the North of England. In all the natural sciences and all departments of engineering the instruction is complete and practical. The laboratories,

chemical, physical and engineering, are well supplied with all necessary facilities for thorough examinations and research. Students to be admitted must be sixteen years old.

The course in all branches of engineering and naval architecture extends over three years; students can then be examined for the degree of B.Sc., two years afterwards for M.Sc., and not less than seven years after that for Dr.Sc., providing they have reached the age of thirty years.

There is a preliminary examination in arts for graduation in science, or there must be shown by the candidates in lieu of it a certificate of graduation in arts at one of the several universities of high rank, including Oxford, Cambridge, Edinburgh, Glasgow, Dublin, McGill College (Montreal), and some colleges and universities of the colonies, or they must show a certificate of having passed the examination for the degree of B.Litt. in the University of Durham.

This preliminary examination assumes a fairly good general education, as will be seen from the requirements for March and September of the past year. Candidates must pass at the same examination in four of the following subjects, of which two at least shall be languages: 1. Xenophon's "Anabasis," Book I. 2. Cicero, "de Amicitia." 3. Souvestre, "Le Philosophe sous les Toits." 4. Hauff, "Die Karavine." 5. Mechanics, hydrostatics, and pneumatics. 6. Euclid, Books IV and VI. 7. English history, William I to Henry II. 8. Geometrical optics. 9. Logic. The subjects of the examinations at the end of each of the three years show that a most comprehensive scientific and engineering knowledge is required.

The engineering laboratory is worthy of detailed mention, as it has some excellent and one, at least, very remarkable engine for experimental purposes. This is a vertical, quadruple expansion, surface condensing steam engine, with four separate cranks, working it up to 200 H. P. — really separate engines, for they can be worked single, double, triple or quadruple expansion at any degree of expansion in each cylinder, with various ratios of cylinders and receivers, various angles of cranks, with or without jackets with steam pressures up to 210 pounds per square inch. A specially designed hydraulic dynamometer is fitted to it and arranged with gear for autographically reading the effective work transmitted through the shaft; it also has all the necessary arrangements for measuring the water — feed, circulatory, and condensed — in jackets, cylinders, and steam chests. This complete ex-

perimental engine was designed by the professor of engineering, R. L. Weighton. One of the remarkable incidents about its construction was, that the plans for separate parts were given to forty-six different manufacturing concerns, and when it was assembled and put together into working shape at the college every part fitted its place perfectly.

There are also horizontal coupled compound steam engines, gas engines, compound Parsons turbine motor and dynamo, testing apparatus of many kinds, machine tools, drills, planes, lathes, etc. The course in this laboratory extends over the three entire years. It is intended to serve two purposes: one to give practical demonstration of the subject-matter of the studies, and the other to provide means for original research for the senior students in various fields of engineering practice. "It is not at all intended as a school for teaching the use of tools, except in so far as this may be acquired incidentally." In fact, the personally expressed opinion of Professor Weighton, who is a practical steam engineer of extensive practice, was decidedly opposed to the method of teaching the use of machines and requiring or permitting the pupils to do work in the school. If they do this, as they go on with the theory they have little appreciation of the work and look upon it as so much recreation and play. He advises the boys to have two years in a shop before they come to the school, then they realize how valuable the theory is going to be to them and do not waste their time. The school has an arrangement with good establishments in the vicinity, where the students can work from Easter to the fall term. In reference to this quite important question, some experience by the Armstrongs is of value. Industrial schools were established by this company at their works to teach boys practical mechanical engineering. The foremen and superintendents of the works taught them, and they did exceedingly well and the project was a success; but the school was turned over to the South Kensington management and the "scientific" professors took charge. It failed from that moment, as the foremen and superintendents were unwilling to teach under their control. They are of the opinion at those works, and from this experiment, that if the boys are to be taught to do actual work it should be done under practical mechanics, and they are of the further opinion that the teaching of machinery work in the schools is a mistake.

Yorkshire College, Leeds. This is one of the colleges of Victoria University; two other colleges are included, University College, Liverpool, and Owens College, Manchester. The requirements for admission to the engineering department is the same in all, which is to pass the Victoria preliminary examination, or present certificates of graduation from other well-known universities in Great Britain. This "preliminary" is practically the examination in the Victoria University at the end of the first year of study, and it embraces English language and history, geography, pure mathematics, and three of the following subjects, one of which must be a language — Greek, Latin, French, German, elementary mechanics, chemistry, and physiology.

The engineering department is not large, as the extent of facilities in the laboratory is limited to sixty students. Notwithstanding its limited numbers, it deserves a prominent place in any category of engineering schools on account of the character of the laboratory facilities, the methods of teaching, and the practicability of its work. The principal professor is Mr. John Goodman, an engineer of twelve years' practice, and thoroughly informed by personal examinations as to the best schools in the United States, Canada, and the Continent; his views and his system of teaching are worthy of some notice here.

The principle underlying the method is that "the scientific training at the college must be regarded as a means of acquiring principles that underlie the art of engineering, and the training in the works as necessary for acquiring the art itself." Which remark, taken from the Calendar of 1897, refers mainly, no doubt, to mechanical engineering. The work in the laboratory consists chiefly of making experiments and testing, and it is definitely understood that "no instruction is given in the use of either hand or machine tools." It is suggested that it would be very well for students before entering the college to have some practical experience in engineering works. The courses of study and the subjects taken up, both in civil and mechanical engineering, cover the whole ground and go to the extent required in any college of engineering, the last of the three years being devoted to the constructive work which the students are to enter upon on graduation.

In mechanical engineering an excellent feature is the illustration of the subjects by an arc light lantern, which is switched on at a moment's notice and used in broad daylight. There are at hand, convenient for this purpose, over 2,000 lantern slides. As it would require too much time for the student to sketch in his notebook from these

views, duplicates of them in photographs, about $2\frac{1}{2}$ inches square, are given out for pasting into the "final copy" notebooks. Skeleton diagrams, taken from the blackboard illustrations, are sketched in the notebooks by the side of the prints. They cost the college a little over one cent each.

The laboratory work is an important feature of the course; two days per week are given to it, and work there is intended to illustrate the lectures and to be done concurrently with them. The experiments are on full-sized work, not "toy" experiments. The 100-ton Buchton testing machine actually tests full-sized bridge ties, struts, columns, rolled joists, girders, rails, chains, ropes, etc.

A lighter testing machine is used for tension, torsion, and bending; another for studying effects of repeated loads on materials; a wire testing machine is provided; also the usual experimental and fully equipped steam engines; an actual Warren girder, 14 feet span, for ascertaining deflections under load; hydraulic appliances; centrifugal pump, lifting 75,000 gallons per hour; Pelton wheel; meter; weirs; etc.

As to examinations, Professor Goodman, in the discussion of a paper by Professor George F. Swain, Massachusetts Institute of Technology, read before the Engineering Congress held at Chicago in 1893, on "Comparison between American and European Methods in Engineering Education," gave his method at Leeds. At the end of the first year he gives the men a problem of some actual work to carry out, and a week in which to do it; when the paper comes in the student certifies that he has had no assistance whatever, and presents full notes of his process. At the end of the second year he gives a set of problems and allows them to use their own notebooks, just as they would do in after life. At the end of the third year an ordinary examination is held and it is done in the ordinary way, a certain number of questions are given and sufficient time is allowed, generally a whole day, in which to answer them.

It is a question whether large available funds for the purchase of workshop, tools, and machinery in this and other schools of Great Britain would not lead to the use of tools and to actual work; that is, if they had the means to do what is done in the Massachusetts Institute of Technology, or Sibley College, Cornell University, would it not be done? To attempt it, however, unprovided with full shop facilities, which nearly all the colleges in Great Britain lack, would, in the opinion of Professor Goodman, be useless and a waste of time.

I believe from the pronounced opinion on this subject by several able educators they disbelieve in that method of teaching, and had they extensive laboratories they would still teach as they do, very much as we shall see it done at Zürich, Switzerland, where we find the finest laboratories in the world.

University College, Liverpool. The well-known Professor H. S. Bele-Shaw is in charge of the engineering department. We are met at once with a near approach to the methods found in some of the largest schools in the United States.

In addition to the usual feature of engineering schools of supplementing the ordinary professional training by systematic technical teaching, with the usual lecture halls, museum, class rooms, and drawing rooms, it has a large laboratory and workshop, where we find various engines, testing machines, and machine tools, "enabling the students to combine practical and theoretical teaching," "the application of scientific principles to practice."

As the same general preliminary instructions and training as in practice is required of all students preparing for any department of engineering, the first two years is practically the same for all. In the third year they specialize in some particular branch.

The same feature prevails here that is found in all British schools and is still observed in after practice, viz.: apprenticeship and pupilage, where the young man becomes an "articled pupil" or "apprentice" in some civil engineer's office, or in some engineering construction works. The course, as usual, extends over three years.

The definite purpose of teaching the use of tools is brought out in the Calendar:

> In the first year students spend four hours in the Woodworking Department, and before proceeding to actual pattern-making are required to do, satisfactorily, a certain number of exercises at the bench and lathe. Seven hours per week are spent in the main workshop at the vise, lathe, and other tools, the object in view being to impart an acquaintance with the use of tools, and some idea of working to a drawing.
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> Students in the second year are required to spend one afternoon at pattern-making, two mornings in the main workshop, and one morning in the testing department. They are allowed to prepare test pieces and experimental apparatus for their own use. Students in mechanical engineering (second year) take a special course of workshop practice instead of surveying during the summer term.
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> Students in the third year go through a series of steam engine trials on the experimental steam engines, gas engines, and other motors, in the laboratory, thoroughly working out all results. In addition to this, experiments on larger engines

are undertaken, with the kind permission of users of power in the neighborhood. A course of experiments on hydraulics is arranged, and also a further course of the testing of materials. The testing machines and workshops are available for carrying out experimental research.

That the college is prepared to carry out this program is shown by the list of machine tools in the workshop, which as one item comprises fifteen lathes for metal work and ten for wood work, with other machines of various kinds for actual work.

The proposition has recently been urged to establish here in this great center of commerce a chair of naval architecture, as at the two great centers of shipbuilding, Glasgow and Newcastle-upon-Tyne.

Owens College, Manchester. This college was founded in 1846 by Mr. John Owen, a Manchester merchant. In 1880 the Victoria University was created with this as its first college, since which date the Liverpool College and Yorkshire College, Leeds, have been admitted as sister colleges.

The college comprises all departments of education and has a special department of engineering, the head professor and director of which is the able Professor Osborne Reynolds. Students on entrance to any departments of the college must be sixteen years of age. It is expected of the student of engineering that he has acquired, prior to entrance, the knowledge needed for the preliminary examination of the Victoria University referred to above.

Here, as at Leeds, the instruction "is not intended to supersede the practical training, which can only be obtained at the office of a civil, or the workshop of a mechanical, engineer." Attendance on a full course of three years is expected of candidates for the Certificate in Engineering.

A laboratory course is considered necessary to complete the education of an engineer, whether mechanical or civil. The making of tests, both for materials and machines, and a reduction of the results are considered an important part of an engineer's work; the training necessary for making these tests is essentially scientific, familiarizing the student with practical mechanics in their higher developments, and by actual examples gives this training a reality, which the present and future development of engineering requires in the engineer. Such are the announced reasons for the laboratory work. From a personal examination of the laboratory in 1891 and 1897, I am satisfied that it combines all that is necessary to carry out the objects above stated.

Department of Engineering in Oxford and Cambridge Universities. Both of these departments are of comparatively recent establishment. Both are provided with the necessary engines and machines for testing in civil and mechanical engineering. At Cambridge there are workshops with lathes and planing, shaping and slotting machines, as well as a forge and other appliances.

There is a staff of skilled workmen to give instruction in each branch of the work. These shops are on quite an extensive scale, but it is understood that the work in them is not intended to take the place of pupilage in a large establishment, but to reduce the time of such pupilage by going into it with a fair knowledge of the use of tools.

The Royal Indian Engineering College, Cooper's Hill, London. This is not only an important and well-equipped engineering institution for the higher technical instruction, but it has developed from very interesting conditions. Its history illustrates fully the state of engineering education at the time of its establishment, not yet thirty years ago, from the fact mainly that it was at that time impracticable to find young men in Great Britain with sufficient technical engineering knowledge and training to take up the Indian work; hence the necessity of establishing this school.

The college is not large in membership, only fifty being admitted annually, its purpose being specially for the preparation of engineers for Indian positions, but it has a very complete curriculum. Candidates for entrance must be between seventeen and twenty-one years of age, the maximum being fixed on account of climatic reasons, older men being more liable to illness in the hot climate of India and less responsive to acclimatization.

The students at entrance must have a good general education, as well as in elementary mathematics, comprising arithmetic, elementary algebra, geometry to the sixth book of Euclid, elementary mensuration, and plane trigonometry and the use of logarithms; the general education must include some classical or modern language.

The course occupies three years; French or German is one of the studies, with more purely engineering studies. Before the graduates can take positions in India, they must go through a course of practical engineering for about a year under a professional engineer.

City and Guilds of London Institute for the Advancement of Technical Education. The institute has two schools, the Central Technical College and the Technical College in Finsbury, both within the limits of London. We will have principally to do with the former. It is an important institution, both in respect to the scope of its work and its high educational character.

It is now about twenty years since quite a number of the Guilds or "Livery" companies of London undertook to meet the new conditions which the rapidly advancing state of modern manufactures required in the character of the workmen to enable Great Britain to keep pace with other countries. Large and accumulating sums were in their hands, bequeathed from former generations. From these they could draw what amount might become necessary to generally improve the industries of the country by improving its technical education.

They wisely referred the project, as to its scheme, to several distinguished men of science and engineers, and obtained a valuable set of reports upon the best means of accomplishing the purpose in view. While the scheme was comprehensive, and combined several minor or auxiliary means of industrial education, the main feature of it was the foundation of the Central Institution for higher technical instruction.

The general features are as follows: Students must be seventeen years of age. The course covers three years. The requirements for admission are a satisfactory examination in elementary mathematics, mechanics, mechanical drawing, physics, chemistry, and either French or German. The first year's course is the same for all students, and is intended to give a thorough preparation for the special technical studies of the second and third years; mathematics is given an important place in the first year, as it is believed to be impossible to attain a high place as a scientific engineer in either of the three departments without a good knowledge of mathematics. These departments are engineering, physical science, and chemistry. The first comprises mainly civil and mechanical engineering, the second chiefly electrical technology, the third the preparation of the student for the higher posts in chemical industries.

The building and its equipment deserve more extended mention than can be given here. I cannot speak too highly of these admirable arrangements. I have examined it twice, once in 1891 and again in 1897, each time in the company of Professor W. C. Unwin, the head professor of engineering. The descriptive and illustrated printed matter

before me covers nearly two hundred pages. The voluminous notes in my journal show my own high appreciation of the school, its methods, its appointments, appliances, and its very able staff of teachers, several of them being men of international reputation.

The building is five stories high. The engineering workshops, laboratories, smithy, dynamo room, dynamo and motor testing room, the physical and mechanical laboratories, and joiners' shop are in the basement. The ground floor is devoted to class rooms and professors' offices. On the first floor is a large reading room, library, and also the physical laboratories and the administrative offices. On the second floor is an extensive museum of engineering, mathematical and physical models, and also the large chemical laboratories. On the third floor is the engineering drawing room, 55 x 67 feet, the remainder being devoted mostly to chemical laboratories.

The mathematical department is thoroughly provided with all the necessary facilities and laboratories for a complete instruction in this very important fundamental study. In the engineering department is a completely fitted up workshop and laboratory. Instruction is given in the former in the use of tools, the idea being mainly to give the student some practical acquaintance with machine tools and the methods of manufacture, so that when he reaches the actual works, if he is to be a mechanical engineer, he will not be so much at a loss to handle himself as he would be without such previous acquaintance with shop work. In this laboratory is a complete outfit of every sort of testing apparatus, from a 100-ton Wicksteed testing machine to a complete set of various kinds of micrometers.

The course of civil engineering is also very complete, but it is considered necessary for these students to have, to a certain extent, a fair knowledge of mechanics, mechanical engineering, and electricity and electrical engineering.

The physical department, under the well-known Professor W. E. Ayrton, is specially devoted to electricity, which is very practically taught and illustrated in the laboratories. These are upon an unusually extensive scale. There are three electrical research laboratories, a dynamo room and a laboratory for testing dynamos and motors; and five distinct laboratories: the junior electrical, the heat, optical, magnetic, and acoustic laboratories, each arranged for making extensive series of organized experiments. The electrical engineering course embraces practical physics, electrical technology, and advanced electrical technology.

From the first day of his course the student learns to make actual measurements in the laboratories. When he has completed his first year he is thoroughly grounded in the science, and has about mastered the basis of the exact measurements of electrical quantities.

The student of electrical engineering in the second year must work several hours of the week at engineering designing and in the engineering workshop, both under Professor Unwin, and several hours also at mechanics and mathematics under Professor Henrici, of that department; on the other hand, mechanical engineering students must give considerable time to electrical technology, for the reason that the use of electrical apparatus in mechanical engineering is rapidly growing.

The chemical department, under Professor H. E. Armstrong, like the other departments, serves a double purpose: it trains specialists, that is, technical chemists and chemical engineers, and gives important and necessary instruction in chemistry to students of the other departments.

Here, also, the student is at once set at work solving definite problems requiring thought and close investigation. The principal object of the course of study is to train young men in the methods of chemical research, so that they may learn to work with independence, for in this way alone can they improve and extend the industries of which they will be later called to take charge.

The intermingling and correlation of the departments are well illustrated by the following course taken from the program for 1897.

GENERAL DISTRIBUTION OF TIME.

The following table shows the weekly distribution of time for all matriculated students of the Central Technical College:

FIRST YEAR.

For Students of any Department:

Mathematics	9 hours
Engineering	7 "
Physics	7 "
Chemistry	7 "

SECOND YEAR.

For Engineering Students:

Mathematics	9 hours
Engineering	12 "
Physics	5½ "
Chemistry	3½ "

For Physical Students:

Mathematics	8	hours
Engineering	10	"
Physics	10	"
Chemistry	2	"

For Chemical Students:

Engineering	10	hours
Chemistry	17	"
Crystallography	3	"

THIRD YEAR.

There will be mathematics from 10 to 12 on Monday and Wednesday for Engineering and Physical students. Also one day per week in the winter term will be taken in a selected department. The rest of the time is given to the work of the department to which the student belongs.

Some important features of this institution appear in a recent report of a special committee appointed by the governors of the guilds, which was instructed to make a full inquiry into the expenditures and the results attained by the institution.

This committee was composed of men of high reputation and great experience. Incidentally, the number of students, as appears from this report, is 210.

The subcommittee reporting on the educational work of the institute approve of the methods, especially of the principle of research work.

As to expenditures, the committee made a careful and comprehensive investigation in the way of comparison with other schools of high standing in the United States and on the Continent, with the result that they found the gross cost per student less here than elsewhere.

They concluded that this institution supplies the highest form of technical education in London, and that its work is of university rank.

It will be noticed in the above account of the Central Institution that no mention is made of mining engineering. The absence of this special department is due, not to the want of appreciation of its importance, but to the fact that it is made a specialty in an excellent institution across the street, the Royal College of Science, with which is incorporated the School of Mines.

This college is supported by the government, and its purpose is to furnish systematic instruction in the general principles of all the branches of physical science to students.

The School of Mines is incorporated with it, the students obtaining their scientific knowledge and training in the principal institution and their special knowledge of mining in the special school, where separate classes are formed for the purpose.

To the general course of study in the College of Science the mining department adds instruction in determinative mineralogy, metallurgy, assaying, and mining operations.

There are two other important engineering schools in London, both well equipped with apparatus for teaching. One of these is a department of the University College, and the other of King's College. In a full account of all such institutions these would have a prominent place.

In the former there is an unrestricted admission of students without examination, and to any class or classes they may select. The complete course extends over three years, but if a student cannot (or thinks he cannot) devote more than two years to study he is accommodated by a special plan, and under it a very large number finish their education in the two years. The study of any modern language is not obligatory.

The same remarks about absence of matriculation examination and freedom to take the whole or part of the course apply to King's College.

The Central Technical College has been given here the more prominent position among these schools, as it is not only a distinctively engineering school, but is the best example of such a school in London.

France.

The methods of engineering education in France cannot easily be compared with those in Great Britain or the United States. As will be seen by the following description, the schools of the highest grade are purely government institutions, graduating government officials, as do our schools at West Point and Annapolis, with this difference, that none but military and naval officers are graduated at our schools, while the most accomplished graduates at the French government schools are educated entirely in civil engineering and become government civil engineers. At West Point the most accomplished graduates, educated almost entirely in military matters, become immediately civil engineers and are placed in charge of all the extensive works of rivers and harbors which, in the United States as in France, are under the control of the general government.

There are three classes of schools in France that graduate civil engineers: first, the Government Schools, a polytechnic school, followed by the *École des Ponts et Chaussées* and *École des Mines*; second, Central School of Arts and Manufactures; third, Industrial Schools.

First: *Government Schools.* These furnish the government with engineers, and have done so for many years. They have also a class of students who graduate as "*élèves externes*" (outside graduates), and they may be French or of any other nationality. Many prominent French engineers have graduated as such, and so have many United States engineers. No doubt these schools, in scope and character of the education given, are equal to any in the world, as is attested by the high order of the engineers who have graduated there.

The regular French students who are able to enter these schools (the number is extremely limited and in accordance with the necessities of the government as to filling up the positions in the service — civil, military, and naval) are admitted after thorough and severe examination. The best university graduates (who have had a course in arts, Latin and Greek) endeavor to enter this school; they are from nineteen to twenty-one years of age. The number of competitors for about two hundred annual admissions varies from 1,000 to 1,800. This gives a first selection of the highest talent and fitness. Of this two hundred, only about twenty (the best pupils) are finally admitted to the engineering schools; the rest of the graduates of the polytechnic school become military or naval officers, with whom we have here nothing to do except to say that after their two years in the polytechnic school they study two years at the military *École d'Application de Fontainebleau*, in the naval school, or in the school of naval architecture. The twenty students above mentioned enter, from the polytechnic, either the *École des Ponts et Chaussées* or *École des Mines*, where the course occupies three years.

It is this *École des Ponts et Chaussées* with which we have most to do in this discussion, and which I will further allude to after saying that the "second" school, Central School of Arts and Manufactures, is made up of those who either were unable to enter the government school or have not attempted to do so. This school is of a high order, however, but not equal to the government polytechnic, and its course covers three years instead of five years. The graduates of this school cannot be admitted to government service, but enter into private practice.

The "third" class of schools is mainly industrial, and their graduates become superintendents, foremen, and mechanics.

Referring now to the twenty students annually admitted into the *Ponts et Chaussées* and *Mines*, they are, from their entrance into this branch of the polytechnic school, government officials, paid as such and invariably given, on graduation, government positions for life. When they graduate from this final school they are usually about twenty-five years of age, and have, of course, a most complete education.

The *École des Ponts et Chaussées* is so well known and has such a high international reputation that it is unnecessary to occupy much time with it. Possibly, however, it will serve to show the scope of the education to simply give the courses of study, bearing in mind that this school is really a school of application, after what would be considered a good engineering course in the United States.

COURSES OF THE ÉCOLE NATIONALE DES PONTS ET CHAUSSÉES.

I.	Applied mechanics: strength of materials
II.	Applied mechanics: hydraulics
III.	Mineralogy and geology
IV.	Constructive materials (technical study and tests)
V.	Routes, locations
VI.	General methods of construction
VII.	Bridge construction
VIII.	Internal navigation
IX.	Maritime works
X.	Railroads
XI.	City and country hydraulics and irrigation engineering
XII.	Steam engines
XIII.	Applied electricity
XIV.	Architecture
XV.	Administrative law
XVI.	Political economy
XVII.	Fortification
XVIII.	Constructive drawings and sketches of railroads, buildings, and machines
XIX.	German language
XX.	English language
XXI.	Photography
XXII.	Fish culture and fishing

Some of these courses may seem to be outside the domain of civil engineering, such as administrative law and political economy, but the details of these courses show that the instruction in them is for the purpose of giving the student that special knowledge of these subjects which he needs in the administration of his engineering works — con-

struction, maintenance, and operation. Thus the railroad course does not confine itself simply to the construction of railroads, but goes into the operation in all its multifarious practical details of organization and handling of the property and the commercial and financial features.

As these government engineers may in war be military engineers, they receive instruction in military engineering and tactics, though this is a subsidiary feature of their education.

Speaking generally of this admirable French school, it would be difficult to find in any country any civil engineering school that surpasses, possibly equals it, in scope, extent, thoroughness, and completeness.

Spain.

A recent correspondence to ascertain the present methods has placed in my hands about three hundred and fifty pages of printed matter, giving the requirements of admission to the government *Escuela Especial de Ingenieros de Caminos, Canales y Puertos* (Special School of Engineers of Roads, Canals, and Ports) at Madrid, the regulation of this school and the detailed programs of the various departments.

The high character of the school will be seen from the fact that the preparatory course for it should occupy four years and its own course is five years.

A careful examination of the results of the programs and a fairly good acquaintance with some of the leading engineers of Spain convince me that this school, in scope and thoroughness, ranks with any in the world.

The requirements proven by a rigid examination are, first, an age of at least sixteen years. To have the degree of Bachelor of Arts, or, being less than twenty-five years of age, to pass easily in the following: elementary arithmetic and algebra, plane and spherical geometry and trigonometry, higher algebra, analytical geometry, descriptive geometry and its application to shades and shadows and to perspective, calculus, lineal, figure, and ornamental drawing and shading, French and English language.

From this course, which the head professor of the school has kindly given me in manuscript, it is clearly seen that the school keeps pace with the modern and most recent advances in applied physics, mechanics, and electricity.

The intention, no doubt realized, is evidently to give the engineer

that broad and extended and thorough education which will fit him for the highest duties which he may be called to meet by the requirements of the present day.

Belgium.

Referring to the methods of engineering education in France and Spain it will be seen that continental methods are radically different from those in Great Britain and the United States. This difference is principally due to greater paternal control. The governments own and operate the water and the rail communications; even if there be any private ownership of railroads the general management must be more or less under governmental control. Government railroads and government waterways must not be subjected to the ruinous competition of unrestricted economical operation by individuals. Consequently the public pay for the water and rail facilities maintained, owned, and operated by the government, and also (and what is the great objectionable feature of state ownership of railroads) the enhanced cost of non-competitive transportation.

The State must have its own agents to build, maintain, improve, and operate its ways of communication, and consequently it undertakes to raise up men for the work by a most thorough and careful method of education, with the purpose, also, of making these officials, in at least the higher positions of service and responsibility, equal in ability to other higher officials of the government, so that they may, by the sheer force of the trained intellect, give the government the most efficient service possible.

While the government universities and special schools are open to all students who choose to avail themselves of the teaching facilities and pay for them, it recruits its servants out of the highest grades.

In Belgium there are two government schools of engineering, one an integral part of the University of Ghent and the other of that of Liege. There are also two other schools connected with nongovernmental universities, Brussels and Louvain. Until within the last five years all engineers on government works had to be graduates of the two government schools, but on the urgent demand of the two latter universities to allow their engineering graduates to compete on equal terms and without prejudice with the graduates of government schools, the State yielded. Now all four schools have an equal chance in these competitions.

It is significant of the high character of the government schools that up to the present time the graduates of the two private schools have not succeeded in bearing off any of these coveted prizes.

In order to understand more fully and appreciate the difference between English and continental engineering education it should be stated here, with the intention of referring to the subject again later on, that in Belgium, and generally elsewhere on the Continent, the principal and controlling purpose in methods is to give the student of engineering a thorough liberal and scientific education, with laboratory facilities for experimental work by the students, both in chemistry and physics and in the use of models, preferring to leave the manual training to his future work, if it is to be of such a character as to require the use of hand and machine tools. He must first be given a liberal and professional scientific education as the foundation for his life as a man, a citizen, and an engineer. The engineers, teachers, and those who direct the methods of education are not in accord with the general English practice.

From the Catalogue for 1897 of the engineering school of the University of Gand (Ghent), and from conference with some of its graduates, now eminent civil engineers, I will give a brief abstract of the requirements and methods. The methods in the universities and schools referred to do not greatly differ.

There are two engineering schools annexed to the University of Gand, the School of Civil Engineering and the School of Arts and Manufactures. The former comprises the following grades: grade of Legal Engineer of Civil Construction, Civil Engineer, Engineer Architect, and Civil Conductor. The latter school has the following grades: Mechanical Engineer, Chemical Engineer, and Industrial Engineer. Each of these two schools is divided into a preparatory school and a special school.

The graduates of the highest grade, first mentioned, may take part in the competition for recruiting the Engineer Corps of *Ponts et Chaussées*, the Corps of Railroad Engineers, and the State Telegraph Engineers. Graduates of all the other grades of both schools can obtain the diploma of electrical engineer after a year of study in the Electro-Technic Institute of Montefiore.

The director of both schools is the administrative inspector of the university. Under him are two inspectors, one of the preparatory and

the other of the special schools. The professors have nothing to do with the general or detailed arrangement of instruction. The director, upon the report of the inspectors of studies, arranges the order of the studies, and the inspectors attend to the execution.

The time required for the highest grades is five years, two preparatory and three special, also for the engineer architects; all the others require four years, two of each, except the civil conductors, which take a two years' course.

The detailed programs of the courses of study are decided upon by the Minister of the Interior and of Instruction, on the proposition of the director of the schools, assisted by the professors.

There is an harmonious arrangement of the studies of the entire scheme to accomplish the purpose in view, viz.: the most complete preparation for the special professional work of each student when he enters upon his life work. The students are not confined to lectures, text-books, and examinations. They engage in graphical works, practical exercises, and scientific excursions and visits to industrial establishments with the teachers, and to works under construction.

The examinations required for admission to the preparatory schools show at once that a high order of education is demanded. To be admitted, the applicant must creditably pass in ten subjects. He must be well up in three languages, his own and two others, a very complete acquaintance with history and geography, of arithmetic, algebra, geometry, plane and spherical trigonometry, analytical geometry to two dimensions, descriptive geometry and design.

The examinations of the three years which students must creditably pass to accomplish the grade of engineer of civil construction are as follows:

FIRST EXAMINATION.

1. Constructions of Civil Engineering
2. Hydraulics
3. Calculations of the Effect of Machines
4. Descriptions of Machines
5. Topography
6. History of Architecture
7. Industrial Chemistry
8. Industrial Physics
9. Political Economy
10. Exercises and problems, practical works

SECOND EXAMINATION.

1. Civil Engineering Construction (2d part)
2. Stability of Constructions
3. Description of Machines
4. Construction of Machines
5. Technology of Elementary Professions
6. Administrative Law
7. Civil Architecture
8. Mineralogy
9. Exercises and problems, practical work

THIRD EXAMINATION.

1. Civil Engineering Construction (3d part)
2. Stability of Construction
3. Application of Machines
4. Railroad Operation
5. Electricity and its industrial application
6. Geology and the Elements of Palæontology
7. Civil Architecture
8. Exercises and problems, practical works

These examination requirements are given entire, as they are characteristic of continental courses of study for professional civil engineers. The varied character and scope of the education will be seen and appreciated; while the grades of somewhat lesser rank do not cover quite so much ground, they are all extended and of wide scope, as will be seen by one more illustration of a course, that of industrial engineer, two years in the preparatory school and the following in the special school, covering also two years.

GRADE OF INDUSTRIAL ENGINEER.

1. Industrial Mechanics (1st part), comprising the calculus of the effect of machines
2. Description of Machines (1st part)
3. Description of Machines (2d part)
4. Analytical Chemistry
5. Architecture
6. Industrial Chemistry
7. Industrial Constructions
8. Problems, sketches, applications, and exercises relative to Nos. 1, 2 and 3, problems of industrial construction
9. Exercises in architecture and problems relative to Industrial Chemistry
10. Laboratory work, visits to manufactories

SECOND EXAMINATION.

1. Construction of Machines
2. Technology of Textile Materials
3. Technology of Elementary Professions
4. Sketches of plans and surveys (part of the topographical course)
5. Industrial Physics
6. Use of Machines
7. Electricity and its industrial uses
8. Political Economy
9. Commercial Geography
10. Problems relative to mechanical construction workshop practice
11. Problems of construction relative to Chemical Arts and to Nos. 2, 3, 5 and 7
12. Laboratory work, visits to manufactories

These various studies are not entered into in a perfunctory or formal manner. There is earnest, thorough, and extended work, both on the part of the teachers and the pupils. These pupils are not lads, but young men old enough to appreciate the necessity for hard work. They are university students, really postgraduates. This will be seen from the fact that, to enter the preparatory school, a six-year course of study in the "humanities" is required and a degree certified to, if the applicant wishes to enter without the rigid examinations already described. These schools are purely civil, and teach no military science as they do in France.

In Holland the education of engineers is carried as far and as systematically as in Belgium. The program of studies in the excellent Royal Institution at Delft, for the year 1897–98, compares very favorably with that of Gand, above analyzed. It embraces the same general courses of study, and requires about twenty professors and fifteen assistants.

SWITZERLAND.

In reference to Switzerland, the whole process of general and special education needs to be stated, but my space will not permit. It may be asserted without fear of contradiction that it is the best educated country in the world. There are no illiterate people, certainly not enough to form a class, and it is contended by leading Swiss educators that not one can be found who cannot read and write except he be of unsound mind or physically disqualified for education.

It might be expected that such a country would carry its professional education to a high point, and it does. Much, very much, may

be learned here of value to other countries. My many months of residence here, made necessary by illness, have not been spent in idleness when physically able to investigate the many interesting educational and social features of the country.

The schools are under the supervision of the government — federal, cantonal, and municipal. "Keeping school is the permanent business of the State," as a writer on Switzerland has well said. When a child, male or female, reaches a certain age, generally seven, the right to stay at home and play ceases; the State seizes the child and holds him fast for years and rears him into what he is to be in life.

From the great educator, Pestalozzi, the principle has been received and consistently followed that education is a developing of the faculties rather than an imparting of knowledge. "Education as the acquiring of information is one thing; it is quite another thing to develop the human forces by a thoughtfully planned course of training, mentally, physically, and normally fitting the student for complete living."

The Swiss method of teaching is never mechanical; it is gradual, natural, and rational; patient, never hurried, a slow but sure advance, and firm ground established as it goes. There are schools everywhere and of all kinds — primary, supplementary, secondary, day, evening, for the blind and the deaf, industrial, linguistic, intermediate, high gymnasium, or American college, university, polytechnic. It is a business which, when nobly done, as here, "brings bountiful return in love of order, law, right, and truth."

But these most interesting general features of Swiss educational principles and practice must give place to the special class of education we are now considering.

The high school, or gymnasium, or college, is the highest state school prior to the university or the polytechnic. About one-tenth of the graduates of the high school enter these higher professional schools; the other nine-tenths go out into life without more preparation, and it is not needed, for the gymnasium course is wisely adapted to their wants, so as to round out the education of the student, boy and girl, and graduate them with a quite complete general education.

The total time required for this education is usually about twelve years, from seven years of age to nineteen, four years in the elementary school, four in the progymnasium (the preparatory high school) and four to four and a half in the gymnasium. In the second the course of study is the same for all, but in four classes with some

variety. In the third it separates into three courses or classes, commercial, technical, and literary; graduates of the first go into business, of the second to Zürich Polytechnic, of the third to the university, into theology, law, medicine, or general literature and philosophy.

The following studies appear in the Calendar for 1897. In Class I, the last year of the progymnasium, Latin, German, French, arithmetic, algebra, geometry, natural history, geography, history, drawing, writing, and gymnastics, and nearly the same studies are pursued in the lower classes.

It will be seen from the above that the student, after those four years of study, is quite prepared to enter upon four and a half more of extended studies along the same lines. As to languages, all four of the following are taught: German, French, English, and Italian, the two former very thoroughly, since they are the languages most in use in this part of Switzerland (Canton of Bern and Zürich), and it should be noted here that in Bern the native language, spoken only, not taught, is Bernese, or, as claimed here, old German. These four languages are taught throughout the entire four years; the remaining studies are algebra, carried quite far; geometry, including analytical geometry, solid geometry, synthetic and problems; physics, acoustics, optics, magnetism and electricity; chemistry, organic and qualitative analysis; natural history, botany, with microscopic demonstrations, etc.; geography, mathematical and physical; art drawing, ancient, middle ages, and Rennaissance; geometrical drawing and practical geometry.

The last half year of the four-and-a-half-year course in the gymnasium is devoted to a careful review of all studies of the course, with some extension of each.

The Zürich Polytechnic School was first prepared for by the Swiss Republic in the Constitution of 1848, which provides for a Government University and a Polytechnic School.

The former has not been established; the latter was, by the law of February 7, 1854, placed at Zürich, and as the university was not to be established, the Polytechnic School was consequently enlarged and extended in its educational scope, so that to the original three sections of civil, mechanical, and chemical engineering there were added architecture, sylviculture and agriculture, and a course in arts and philosophy, and also a pedagogic course.

From its inception it has been the main purpose to maintain a school of superior technical instruction and training, and to give its

students, in the highest possible degree, scientific maturity for the various vocations for which they prepare themselves. It labors also to turn to the practical advantage of its students scientific theoretical researches, endeavoring always to unite in a reciprocal influence science and practice, believing that the present age has a need of highly cultivated and fully prepared technical men.

The course of study, the general and detailed methods, all conspire to accomplish this high purpose. The professors and teachers are selected with the greatest care, and among the former are men of the highest international reputation as instructors and practical scientists.

The students not only attend the lectures and work in the drawing room, but in the extensive laboratories in experiments and in original research. The great enlargements and extensions in recent years of the various laboratories show what importance the management gives to this feature of the studies. It may be mentioned here that in addition to the present buildings and laboratories referred to below, a laboratory for mechanical investigation, like the best of those in the United States, was not long ago proposed by one of the leading professors in civil engineering, Professor W. Ritter, and the proposition is now on its way towards realization.

No fixed system prevails (nor will it ever); from year to year the methods vary to suit the ever advancing state of practical science.

In the direction of tests of all kinds, and in the development of electrical facilities, unusual advances have been made recently. Through the efforts of Professor Weber, whose fame as an electrician is international, a suitable building and a very extensive electrical apparatus have, within the last year, been opened up, attracting by its remarkable character a pilgrimage of electrical experts from all parts of the world to study with the facilities and engage in original research.

As to the testing facilities, I have but to state that it is in charge of Professor Tetmajer to stamp the facilities and their use with the highest mark of perfection; so extensive and complete are they that the International Association for Testing Materials is established here under Professor Tetmajer, the president of the association.

The progress of science and of "technique," widening and extending their domain, making in consequence greater and more rigorous requirements for the preparation of technical men, have little by little forced a longer course of study in the special divisions, particularly in mechanical and electrical engineering, also in chemistry.

Including the whole seven divisions of the school, there are 167 separate and distinct courses of instruction that are obligatory, and 114 that are not obligatory, a total of 281, of which 40 have not yet been put in practice. There are regular students and attendants on lectures (*auditeurs*). This year, 1897–98, there are 858 of the former and 307 of the latter, a total of 1,165. Of the regular students, 516 are Swiss and 342 are from 20 different foreign countries, Austria-Hungary leading with 82, Germany following with 67, Italy with 33, Russia 28, Roumania 22, America (all America) 22, Great Britain 15, Holland 13, Scandinavia 12, and other countries with lesser numbers. The number of the regular students has increased from 562, in 1871, to 858 this year. The teaching staff is as follows: 60 professors, 44 honorary professors, 43 assistant teachers, assistants and private docents; total 147.

A school of this magnitude, and it may be said that the buildings and facilities are adapted to this large number of students, must exert a commanding influence on technical education and must send out to many countries competent professional engineers. It therefore deserves some detailed mention, from which a lesson may be learned for establishing similar schools elsewhere. The principle of obligatory study, obligation to conform strictly to rules, to be present at recitations and all other fixed functions, is absolute. The opposite course of freedom to students to do as they please is considered subversive of good and necessary discipline, so that the *auditeurs* must conform to all the rules and regulations and punctually attend upon the instruction. These *auditeurs* are principally found in the arts course, into which such a class of students can be admitted without fear or scruple.

The minimum limit of age is eighteen, and the applicant must have completed fully his eighteenth year. A certificate from a preparatory school of high standing and exacting requirements is accepted in lieu of an examination. The age of eighteen was decided upon in 1882, to make it more sure that the student should not be immature in his preparation.

The examination for admission is severe, and the necessity for this lies in the conviction, from long experience, that it would be extremely detrimental to the school, the students, the professors, and its development to admit students insufficiently prepared.

The examination of candidates for admission is first on general culture, and second on special subjects. In the first, orthography, style,

and logic are required in a thesis to be written in his own or any language he may select of four — German, French, Italian, or English.

He must give oral proof that he is sufficiently acquainted with the language in which the course he enters is to be taught to understand the instruction. He must submit to an oral examination in the history of literature, political history, and the natural sciences.

In the special subjects, quite extensive knowledge is required of arithmetic and algebra, of geometry to the construction and solution of problems, of stereometry, plane trigonometry and elements of spherical trigonometry, analytical geometry and conic sections, descriptive geometry quite complete, physics, elements of the theory of movement, mechanics of solid, liquid and gaseous bodies, theory of heat, knowledge of the principal phenomena and laws of magnetic and electric forces, chemistry, simple and compound bodies, atomic theory, etc., drawing, in line and figures, facility in the execution of geometrical problems and some skill in coloring, freehand drawing and some exercise in ornamental design.

Coming now to the courses of study, it would be manifestly impracticable to give more than the most general idea of them.

The school of Architecture requires three and a half years. Beginning with higher mathematics it extends to the study of styles, and includes all the knowledge required by a professional architect, such as mechanics applied to construction, art of the civil engineer, designs of ornamentation, hygiene of buildings (sanitation), modelling, and history of ancient art.

The school of Civil Engineering also requires three and a half years. Beginning with the differential calculus it extends to electrical technology, and includes, among other things, higher mathematics, architecture and civil construction, physics, topography, study of machines, industrial geology, topographical designs, graphical statics, construction of roads and railways, foundations, water works and canalization, practical geodesy, technology of constructive materials, stone and steel bridges, and study of law.

The school of Industrial Mechanics covers the same period and is fully extended, branching into more mechanical work, including the construction of machines and turbines, and other hydraulics. Electrotechnology is gone into much further, and the principles, apparatus and methods of measurement of electricity, telegraph wires and cables, and a thorough course in the electrotechnical laboratory of Professor Weber,

motors, dynamos, installation of manufactories and electric central stations.

The school of Industrial Chemistry is very complete in its course and is also three and a half years in length, going as far as the installation of various kinds of chemical works. This course requires abundance of room, and this it has in a very large building specially and intelligently designed for the purpose. There is attached to the course a section of pharmacy, requiring two years.

The Agricultural and Forestry School requires three years, and fits the young man for professional work of this kind, so important in Switzerland, where the greatest possible advantage must be taken of the rather meagre conditions to promote their highest usefulness. The course, however, gives training of use in any country. This course is thorough in agricultural chemistry and all the allied studies.

The Normal School of Mathematical and Natural Sciences carries all these and related subjects to great perfection, and turns out teachers of a high order of merit.

The Seventh Division is really a university extension course in philosophy and political economy; with it is a technical course in photography, applied topography, calculation and construction of roofs, ice machines, operation of railways, industrial hygiene, the technic of the telegraph and telephone, etc. In this division is placed military science, which is carried to great perfection in Switzerland.

The buildings are six in number. In the main building are architecture, civil engineering, mechanical engineering, normal school of mathematics and natural sciences, philosophy, political economy, and the library. Chemistry is in a large building, agriculture and sylviculture in another, physics in another, and there is a good astronomical observatory. Recently the sixth building for electro-physics has been completed, and one to be used as a laboratory for mechanical investigation above referred to will soon be commenced.

The Polytechnic is supported partly by the tuition fees and partly by the federal government, the city of Zürich, and by nearly a million francs of bequests.

I will only remark in closing this sketch, that while the laboratories are unequalled in the world and the electrical department better equipped than any other, they are used for illustration, testing, experiments, and research, and not at all for manual training in the use of tools. The old method of confining the tests to illustrations of prin-

ciples by the teachers is still employed, but in recent years the importance of testing materials has grown so rapidly that special courses have been established at Zürich in which the students are taught to execute tests themselves.

There is one important feature of this school which distinguishes it from most of the German and Austrian schools and from the general continental method. In these other countries, particularly in Germany, the students are not compelled to attend the lectures which belong to the course. They enjoy what is called "*Studienfreiheit*" (freedom of studies). There are no recitations; the students are obliged to pass through only two examinations during the entire course. The students, after their long, confining, disciplinary course in the gymnasiums and other preparatory schools, are now let loose, as it were, and they revel in the new freedom and make the most of it, often, possibly, to their detriment.

At Zürich it is entirely different. There are weekly recitations in every important course, promotions are made annually, and certificates are given the students semi-annually. Those who do not apply themselves to their studies are sent away. All this induces more earnest study and work than in the German schools.

If one takes the pains to question engineers of high standing in Austria, Hungary, and possibly Italy and other countries, he will discover that the fact of graduation at the Zürich Polytechnic is considered a sufficient guaranty of possessing the best and highest possible engineering education in all Europe. It is always with pride and confidence that the engineer answers the question as to where he was educated by saying, "I studied at Zürich," even so far away as Budapest or in Roumania.

Germany.

The thorough, systematic, scientific education of Germany places it high on the list of educational countries. Germany was formerly (and is still) the Mecca of those postgraduates of our country who desired to go beyond the ability of American universities and colleges and beyond their courses of study, and also beyond the professional courses of study in law, medicine, and engineering, as well as in special studies.

The engineering schools could not, in their special methods, be further improved. They were on the top and secure there, and the same may be said of purely technical and industrial education, which

has done so much for German mechanics, artisans, tradesmen, merchants, and commercial men. All these departments of industrial education are supervised and controlled by the State. The result has been that the Germans at home and abroad have commercially distanced the British, in new countries particularly, and have invaded the world's markets with their industrial output, and to such an extent have they interfered with British markets that a genuine alarm has been sounded in Great Britain, not by the educational enthusiasts alone, but by the conservative merchants and manufacturers, resulting in appeals for a higher and more thorough technical education. Secondary education is receiving just now more attention in Great Britain than ever before. Committees of investigation have been sent from Manchester and other industrial cities to Switzerland and Germany to study the methods of education, returning to their homes with unanimous reports of the superiority in every direction of the continental methods, with the prophecy that trade will be entirely lost and they will be distanced even more markedly than now if something is not done to remedy the existing unsatisfactory methods of industrial education.

We would naturally expect to find, not only the perfection of industrial education in Germany, but of professional engineering education as well, at Charlottenburg, Munich, Dresden, Hanover, Braunschweig, Darmstadt, Carlsruhe, and Stuttgart, and we do find it, especially in scientific education, as well as in experimental and research methods with the new apparatus for this work now being installed.

As characteristic of these royal technical high schools, Hanover may be taken as a fair sample of all. I have before me the *Programm* of 1897–98. Students are admitted who have graduated at the gymnasium of the first order, like that described above, at Bern. There are four departments, architecture, civil engineering, mechanical engineering, and the school of chemistry and electrotechnology and of general engineering.

The extent and thoroughness of the courses may be seen by taking that of mechanical engineering for illustration, which carries the student from his one year of practice in the shops after his graduation from the *Real Gymnasium*, through four and one-half years of instruction combined with laboratory work, from the scientific principles to the most advanced practical studies. Perhaps a better idea of the extent, thoroughness, and practicability of the course from beginning to end

may be gathered from a letter recently received from a prominent German educator, a professor in one of the best royal technical high schools.

It describes the course of education required by a mechanical engineer to enter the service of the government: from six to ten years of age in the primary schools preparing for the *Real Gymnasium;* from ten to nineteen years of age in the latter school; from nineteen to twenty in practice, one year in a workshop manufactory, though it is better to take this year of practice after a year in the military service; from twenty to twenty-five, four and a half years in the *Königliche Technische Hochschule* (Royal Technical College). At the end of two years in this college a thorough and rigid examination must be passed, and at the end of the course the final examination; success in this latter examination secures appointment as Director of Government Construction. There must then be two years of practical work in government service, and then follows an examination by the state for the final diploma.

Those who wish to enter the high service of the government as mechanical engineers must take three semesters in the university in jurisprudence and political economy.

As to laboratory methods, a remarkable change has taken place within the last few years. When I examined into this question in 1891, there was perhaps only one school (Munich) which had a steam engine for laboratory work; now all of them are fairly well equipped with a steam plant, and rapid strides are now being made in all the royal technical schools in equipping themselves with complete apparatus.

The industrial and commercial activities and ambitions, in scientific and practical directions, have given an extraordinary impulse to technical education. This has resulted in the "installation" of ample and richly equipped laboratories for engineering in connection with the engineering departments of the high schools. "All these new plants will be much larger and of wider range than ours at Munich. They are not yet finished, but in a year or two you will be astonished at seeing that we are equalling the Americans in their kind of engineering education."

"I must add, to avoid a misunderstanding, that there is no manual training at all in these laboratories; that is, we have no workshops in connection with the technical high schools, but we send the young men to practical engineering work for practical training."

The above is from a letter recently received from the director of the Munich Royal Technical High School.

I have before me descriptions and illustrations of two of these new plants, one at Darmstadt and the other at Stuttgart. They are very complete, and, being entirely new, are in accordance with the latest experience of the world. The designers have evidently personally studied all the prominent plants on both sides of the water, and have taken advantage of the good qualities and have avoided the defects of others. In the development of laboratory methods, plant and facilities, what, as in naval development, was considered suitable ten years ago is now often only fit for the scrap pile. The German technical colleges have profited by all this experience. It will soon be profitable for American technical teachers to visit these new laboratories and study their design and adopt their excellences.

As might be expected, electricity has been given a prominent place in these laboratories.

We find at Hanover all the testing machines needed for testing the strength of materials, for experiments on the flow of liquids in the face of the wind, air compressors, discharge of water through orifices, determination of contents of velocity of flow, indicators with steam, gas and petroleum engines and turbines of various kinds, with a variety of dynamos, and with many attachments for measuring electric forces.

From a letter just received from Professor Hempel, of the Dresden Royal Technical College, I learn that they have there a complete outfit of various kinds of experimental machines: three steam engines of varying power, gas, petroleum and water motors, experimental boiler, testing machines of various kinds, and an electric institute with a variety of dynamos and their attachments; and further, that this spring two new institutes will be commenced in connection with the college, each costing 800,000 marks ($200,000).

Notwithstanding the present advanced state of technical education in Germany, there is dissatisfaction and unrest and ambition for better methods, more in respect to the *personnel* than the laboratory. One of the most learned advocates of the more practical teaching is Professor A. Reidler, of Charlottenburg, who has written much earnest argument in favor of ingrafting into German methods more practicality and doing away with some of the present dogmatic teaching, which may be called a German national characteristic, which is unlike the common sense characteristics of the Anglo-Saxon peoples. He considers it necessary

to give the students "more thorough knowledge by means of practical application by teachers who understand such application and work in the spirit of true *practice* and *economy*. The teachers of the technical sciences must be acquainted with the actual facts from their personal activity, and must be masters of, and know how to put into practice, the art which they undertake to teach."

The following will apply anywhere in the world, and is in accord with the principle in full activity at the University of Chicago, where the professors and the teachers in all departments are expected to accomplish some original work and to be in earnest.

"In the technical colleges a lively *mental competition* of the teachers ought to be produced by parallel professorships and by attracting teachers from practical life. The success of the colleges and of the national productive activity is dependent upon this. The damaging of an entire generation and nation by a single college teacher who is not capable of doing his work, or whom a false or outlived reputation surrounds, is much greater than the damage which dozens of dismissed army officers would have been able to do."

If the earnest spirit and purpose and the suggestions so forcibly put become a part of German education, as they are likely to become, it can be seen that nothing but the best of schools and methods and spirit of instruction will ever be able to hold back our young men from Charlottenburg and other German centers of education.

Italy.

Any one at all familiar with Italy and its works on land and sea must come to the conclusion that these excellent constructions have behind them the best methods of engineering and architectural education. The skill of the old Romans has evidently been transmitted to their descendants. The Italian maritime engineers (I am not much acquainted with the works of other kinds) combine happily the good common sense of the British and the precision and good taste of the French. Their works are made to stand, and their proportions and designs are elegant and artistic.

I have now for the first time had an opportunity of becoming acquainted with the methods of engineering education prevailing here, through the kindness of Professor Guiseppe Colombo, member of Parliament and the director of the *Institute Technico Superiore* of Milan,

and late minister of public works; and by the assistance of Professor L. Cremona, Senator (vice-president of the Senate), and the director of the Engineering School of Application at Rome.

The programs of these excellent schools show them to be equal, in respect to the curriculum, to any of the schools of the Continent.

These are royal schools and managed by the government. There are others similar at Turin, Padua, Bologna, Naples, and Palermo.

The government engineering service, which recruits its engineers from the schools above mentioned, is very extensive and requires many engineers. The Ministry of Finance deals with all sorts of products, such as tobacco, spirits, powder, matches, salt, etc. The Public Works Department includes within its control maritime and inland navigation works. The Department of Agricultural Industry and Commerce is concerned with irrigation, the execution of laws relating to manufactories, electrical transmission, and topography. So that the government engineers require training and knowledge of various kinds, in order to be fitted for the duties of these various departments.

Employment by the government requires not only diplomas of graduation from the government schools, but in addition special examinations, which are periodically carried on at Rome, and relate to the studies particularly required in the branch of public service to which the candidate makes application for entrance.

In order that the engineering student may enter either the university (in which he must pass two years in the mathematical section before being admitted to an engineering school) or the preparatory school of the superior Technical Institute of Milan (which was founded in substitution of the two years of the university), it is necessary for him to have a diploma of the Lyceum, or of a technical institute. (The technical institutes are schools of secondary instruction, without Greek or Latin, and with special scientific courses.)

There are no limits to the age of entrance in the schools of application, but the requirements are such as to raise the age above that usually found in the entering class of American or English technical colleges. The whole course of study would be something as follows: The boy, at eight or nine years of age, enters the elementary school, which holds him for about four years; then the Gymnasium, Lyceum, or Technical Institute keeps him five to six years, the University (or the preparatory school of Milan) two years more, the School of Application three years more — total educational course fourteen to fifteen

years. He may then, if he has passed all through successfully, receive the diploma of engineer, at, say, twenty-three to twenty-four years of age.

At the Milan school there is a mechanical laboratory, with steam engines, gas engines, pumps, turbines, and other machinery for testing and experimental purposes, with a special laboratory for testing the strength of materials. The manual training method is in use at Milan for the special purpose of training the industrial section, which comprises about one-half of the students. These students are sent periodically to remain some days in several engineering workshops, so as to watch the process of casting, tool working, and the use of machinery. At the end of the yearly studies all the students make a journey together, under the direction of one of the professors, to examine the most important works of various kinds in the country, in civil engineering, railways, bridges, harbors, etc., and also some of the important manufacturing districts. Often during the semester the students are taken by the professors to workshops and factories to illustrate the studies in the various courses as they proceed with them.

There are two special electrical institutes in Italy, one in Turin and the other in the Polytechnic at Milan, the former particularly supported by local funds, and the latter an entirely private enterprise founded by the late Mr. Erbay, a great manufacturer of Milan. Both these institutes have special laboratories for conducting all manner of electrical tests, and are well supplied with dynamos and all other electrical apparatus required.

At Milan, also, in addition to this electrical course, there are three sections, civil engineering, mechanical engineering, and architecture.

The other royal schools above mentioned graduate only civil engineers and architects, and the total number graduated per annum in all the schools is about three hundred, with about fifty industrial engineers at Milan. The total number of students in all the schools is about twelve hundred.

An examination in detail of the school at Rome, in company with several of the professors of agriculture, chemistry, electricity, and civil engineering, showed this school to be well equipped in all departments. As it is purely a civil engineering school it would not be expected to have a large steam engine plant, but it has a good equipment for testing materials, and a dynamo plant with every kind of metre for measuring electrical forces and conditions.

The architectural department is not large, but gives the highest instruction under the charge of Professor Enrico Guj, one of the leading architects of Rome. He is vice-director of the school, presiding over it in the absence of Senator Cremona, who is vice-president of the Roman Senate.

Russia.

There are two polytechnic schools, at Helsingfors and at Riga, with four or five faculties, like the polytechnic schools of Germany, and their courses of study are much like those of the German schools.

There are besides these three technological institutes at St. Petersburg, Moscow and Rarkoff, with two faculties, mechanical engineers and chemistry, also two institutes for railway and bridge engineers. These are at St. Petersburg and Moscow. At St. Petersburg there is one institute for mining engineers, two institutes for architects, and also one institute for electrical engineers; this is specially to educate electrical engineers for the telegraph department of the government. Two years ago a technological institute was founded in Tomsk, Siberia. This year two polytechnic schools will be established in Kieff and Warsaw.

All the technical schools are established by the general government except the Riga School, which was founded by the municipality and the merchants. The government, however, is to give an annual subsidy to this school, and its graduates will have the same status as those of the government schools. All students must pass an annual examination successfully in order to pass from one class to a higher or to receive a diploma. Only graduates of these schools can engage in government service — on harbors, railways, telegraphs, architecture, bridges, etc.

To enter these schools the student must have graduated from a *Real Gymnasium*, as in Germany. Greek and Latin are not required; there is no limit to the age of admission. Steam engineering laboratories are just now being introduced into the technical schools. Students in mechanical engineering are obliged to work as workmen in the workshops in the vicinity, and to finish a series of bolts, screws, keys, valves, parts of machines of various kinds, etc.; also to learn to take off indicator diagrams from steam, gas, or petroleum motors.

United States.

Massachusetts Institute of Technology, Boston. This important school of technical education is so well known, both in the United States and in Europe, that there need be given only its salient features for the purpose of comparison with European schools and methods. It may be properly styled a scientific school applying its science to the useful arts. There are thirteen distinct but correlated courses of study, embracing civil, mechanical, mining, and electrical engineering, architecture, naval architecture, chemistry and chemical engineering, and courses in physics, geology, and biology, and following the last, sanitary engineering. There is also a course in "general studies" to prepare students for trade, banking, etc., requiring a knowledge of political economy and kindred studies. Admission requirements are expected to meet the case of students graduating from the ordinary American high school (not the German *Hochschule*, which is really a technical college, but like the German *Real Gymnasium*), or from the English and scientific departments of the preparatory schools for college. The examinations embrace algebra, plane geometry, advanced algebra or solid geometry, history, French or German, and English grammar and composition. The examinations are quite rigorous, and many applicants are rejected. They are expected to compel maturity. The average age of students on entering is somewhat over eighteen years, the same age as at Zürich, except that at the latter eighteen years is a requirement, and a rigid one, where if the year, for instance, begins in October and the student is eighteen in November, he cannot enter. At Boston there are some few students sixteen years of age at entrance; the ages range from sixteen to twenty-two, the average being eighteen years and eight or nine months.

The length of the regular course is four years. The aim of the course is to make the pupil observant and exact, to give him a desire and ability for research and experiment, to give him a good foundation in those studies which underlie the practice of the scientific profession, and to give him all the practical and technical knowledge required for this purpose.

There are six buildings, all within convenient distance of each other. Everything is on a large scale, and it must be to take care efficiently of about twelve hundred students, the number taught in 1896–97. There were, in the same year, 153 teachers, including professors, associate

professors, assistant professors, instructors, assistants, and lecturers. The students come from thirty-nine States of the United States; the larger number, or about sixty-one per cent., were from Massachusetts; twenty were from foreign countries. Since 1890 twenty-nine foreign countries have had representatives in the lists of students.

There were last year eighty graduate students[1] engaged on special studies; sixty-nine of these are from other institutions, some of them being the foremost colleges of the country. Women are admitted to many of the courses; there were seventy-one in 1896–97.

The degree of Bachelor of Science (S.B.) is given for the successful completion of any of the four-year courses, followed by advanced degrees upon completing advanced courses at the Institute.

To go into the details of the equipment of the buildings would be impracticable. All of them for their various purposes are completely equipped with everything required for teaching, illustrating and experimenting, and for research work. While there are extensive workshops they are not considered "factories" but laboratories. "It is not the thing made, but the training, the discipline, the practice, which the student obtains in the making."

A brief summary of the equipment must certainly be given, otherwise no adequate idea of the scope and extent of the school could be formed. In the woodworking department are forty carpenter's benches, two circular saw benches, a swing saw, two jig saws, a buzz planer, a mortising machine, thirty-six wood lathes, a large pattern maker's lathe and thirty-six pattern maker's benches. The foundry contains a cupola furnace, two brass furnaces, a core oven and thirty-two moulder's benches. The forge shop contains thirty-two forges, seven blacksmith's vises, and one blacksmith's hand drill. The machine shop contains twenty-three engine lathes, seventeen hand lathes fitted with slide rests, two machine drills, three planers, a shaping machine, two universal milling machines furnished with spiral and gear-cutting attachments, a universal grinding machine, a cutter and ream grinder, a 24-inch standard measuring machine, thirty-two vise benches arranged for instruction in bench work, and a fully equipped tool room. A power hammer will be added to the equipment of the forge shop during this year. It will be noted that this equipment is not in the laboratories or for laboratory work.

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[1] The number during the year 1902–03 is 161, out of a total of 1,608 students.

There are practically eight distinct laboratories: for physics, chemistry, mining and metallurgy, engineering (including applied mechanics and hydraulics), biology, architecture, and geology, and the mechanical laboratory, or workshop, above mentioned.

There are eighteen separate rooms in the laboratory of physics alone, many of them of large size, devoted to general physics, electric dynamos, electric engineering, heat measurements, physical chemistry, acoustics, and optics. The laboratories comprise in all thirty rooms. The engineering laboratory is very complete and extensive, occupying two floors in the large engineering building; it comprises steam engineering, hydraulics, testing, and a room for cotton machinery.

The steam department has a triple expansion engine of 160 H. P., with smaller steam engines. The hydraulic laboratory contains a closed tank 5 feet in diameter and 27 feet high, connected with a standpipe 10 inches in diameter and 70 feet high; all necessary connections are made with it for every variety of hydraulic experiments, and one finds all sorts of hydraulic metres, pipes, gauges, weirs, various orifices, nozzles, etc.

The laboratory for testing materials has, first, an Emery testing machine of 300,000 pounds capacity, also one of 100,000 pounds, for testing transversely.

The biological laboratory is unique and important; it is used mainly for the purpose of the investigation of the physical, chemical, and physiological conditions of sanitary problems in water supply engineering.

In the architectural laboratory are not only all the modelling apparatus required, but a complete plumbing system for study.

The geological laboratory provides for mineralogy, lithology, and structural and economic geology. These various departments and laboratories have conveniently at hand their own departmental libraries, some of them quite extensive and all well selected. There is also a large general library. All books and all instruction in the laboratories have for the main purpose the teaching of scientific and practical engineering. The total number of volumes and pamphlets in all libraries is about 55,000.[1]

It may again be remarked here that it is the purpose always to make *professional* engineers, not mechanics. All work in laboratories

[1] The present number is about 80,000. — ED.

and shops is considered as so many problems, teaching various operations and the use of the appropriate tools, the work being considered necessary from the point of view of mental as well as manual training.

To give the various courses of study covering all departments would be impracticable, but in order to convey an idea of them one will be given, that of electrical engineering, the five years' course, which comprises the same studies carried to the same extent as the regular four years' course, it being instituted to permit students to take a year's extra time for the course.

VI. Electrical Engineering.

FIRST YEAR.

First Term.	*Second Term.*
Algebra (or Solid Geometry)	Analytical Geometry
Plane Trigonometry	Plane Trigonometry
Rhetoric and English Composition	Political History since 1815
French or German	French or German
Mechanical Drawing	Mechanical Drawing and Descriptive Geometry
Freehand Drawing	Freehand Drawing
Military Science	Military Science

SECOND YEAR.

First Term.	*Second Term.*
General Chemistry	General Chemistry
Chemical Laboratory	Chemical Laboratory
Carpentry and Metal Turning	Carpentry and Wood Turning
Differential Calculus	Integral Calculus
Descriptive Geometry	English Literature and Composition
English Literature	German (or French)
German (or French)	
American History	

THIRD YEAR.

First Term.	*Second Term.*
Acoustics	Physics
Physics, Mechanics, Wave Motion	Physical Laboratory: General Physical Measurements
Electricity	Magnetism, Electricity
Principles of Mechanism	Mechanism, Gear Teeth
German (or French)	Machine Tools
Political Economy	Drawing
Business Law	German (or French)
	Political Economy and Industrial History
	Business Law

FOURTH YEAR.

First Term.	*Second Term.*
Physics: Heat	Physical Laboratory: Heat and Electrical Measurements
Physical Laboratory: General Physical Measurements	Theoretical Electricity
Theoretical Electricity	Electrical Measuring Instruments
Methods of Telegraphy	Steam Engineering, Boilers
Steam Engineering: Valve Gears, Thermodynamics	Engineering Laboratory
Drawing	Drawing
General Statics	Strength of Materials: Kinematics and Dynamics
Method of Least Squares	Precision of Measurements

FIFTH YEAR.

First Term.	*Second Term.*
Technical Applications of Electricity	Technical Applications of Electricity
Physical Laboratory: General Electrical Testing	Engineering Laboratory
Theory of Alternating Currents	Differential Equations
Photometry	Thesis
Steam Engineering	*Options*
Dynamics of Machines	Physical Laboratory
Hydraulics	Mathematical Theory of Electricity
Engineering Laboratory	
Strength of Materials: Friction	

Worcester Polytechnic Institute, Worcester, Mass. No doubt this excellent school, presided over by Dr. T. C. Mendenhall, of international reputation as a leading practical scientist, takes front rank with the best schools of the world.

The requirements for admission are a minimum age of sixteen years; average age is actually over eighteen.

Examinations must be passed successfully in United States history, English language, algebra, plane and solid geometry, French or German. In reference to the English, the requirements, beginning in 1899, are those adopted by the New England Association of Colleges and Preparatory Schools. All the subjects above mentioned must be fully understood. A suggestion is given in the requirements that it would be advisable, before applying for admission, to take a full high school course, "including, if possible, such knowledge of Latin and Greek and ancient and mediæval history as is generally required for admission to college."

At the date of founding the institution, 1865, and in the generation preceding, any one desiring to enter a branch of the engineering

profession had to serve for a longer or shorter period with some expert practicing engineer as an apprentice, and pick up what professional knowledge he could, under often very unfavorable conditions. If he began this apprenticeship in early life he was forever held back from a high and useful position by the lack of a liberal education. If he obtained the latter before he entered upon his engineering work he had still to begin at the bottom to learn the rudiments of engineering.

The object of founding the Institute was to combine in the school two essential conditions of success — study and laboratory work. As to the laboratory, a distinction is made between machinery and manual training. The dominant idea is that the former is essential, and in these days of machinery development the latter is not, except for the mechanic and artisan, which the school does not pretend to send out.

"In the so-called manual training schools, or in trade schools, this other is, and sometimes must be, the end in view; but in the education of the engineer exercises in the workshop should be planned and conducted so as to furnish a discipline and a training of a distinctly higher order."

In the very extensive workshops this end is always kept in view, and the greater part of the output of the shops "consists of special machines, appliances and devices which have been originally designed and developed there, and which represent the result of actual engineering practice on the part of the students and professors." These extracts are from the Calendar of 1897–98.

There are five courses of study: mechanical, civil, and electrical engineering, chemistry, and a general scientific course. They are each four years in length, with an opportunity for an advanced year's work in electrical engineering.

The plan of instruction is by lectures, recitations, and laboratory and workshop practice. The scope and extent of each course is fully as great as that of the Massachusetts Institute of Technology previously mentioned. The laboratories are equipped with the latest and best machines and other appliances for all manner of experimental work and tests.

Engineering as a Learned Profession.

We have now taken all the space and time at command in outlining the methods of education in many countries. The national differences

appear plainly, and need not even be summarized; it might lead to invidious comparisons to do so, and consequently to criticism and misunderstanding. I must leave you to form from the description your own conclusions as to which country or countries possess the best methods. What is best for one may not be for another; "circumstances alter cases" in nothing more than in educational methods. What might be necessary for a young man to have in the way of training in Worcester, Massachusetts, might not be at all suitable for a young man in Worcestershire, England, or in Bern, Switzerland. What I wish to present ultimately is the character of the school that ought to be founded in connection with the University of Chicago. I must, however, call attention to some developments of the general subject and to some features of the development of engineering itself as a learned and important profession.

Referring first to Great Britain, the birthplace, almost, of modern engineering, it may well be said that the subject of engineering education has there received great attention in the way of investigation, at least, by the Institute of Civil Engineers, in London, the largest and confessedly the most important and highest institution of the kind in the world.

As long ago as 1870 the subject was fully inquired into by the council, again in 1891, and successive presidents of the institution have considered the subject important enough to give much space to it in their inaugural and other addresses. More important still are the recent orders of the council to require a scientific and practical training and knowledge on the part of student and associate members, to be attested by examinations conducted by the council, or by diplomas and degrees from specially designated schools and universities.

We may, therefore, at the outset conclude that the "rule of thumb" engineer will have no opportunity to show his ignorance in the future. In fact, it may be stated broadly that the civil engineer of the twentieth century must be an educated man, and specially prepared for his life work by the highest order of educational instruction and training.

But it has not always been so; steam and electricity, the potent forces of the present time, have been developed in little more than half a century. They, more than any other causes, have produced the civil engineer and raised him to rank with the older "learned" professions. He starts with the twentieth century on the same high level with them, and it is the circumstance of this situation that calls for that sort of education that will best meet this condition of affairs.

It is instructive and interesting to read the literature of the last thirty years as it appears in the proceedings of the Institute of Civil Engineers, and it is amusing, almost astonishing, to read in extracts from a lecture on "The Education of Civil and Mechanical Engineers" in 1868, by Professor Fleeming Jenkin, delivered in the University of Edinburgh, the description of the attainments of young engineering "apprentices" and "pupils" in workshops and engineers' offices:

> Young men, at the age of about eighteen, enter the office of a civil engineer. Usually few questions are asked as to previous training. Etiquette requires the engineer to show a certain reluctance to receive the pupil, and, in fact, the ordinary pupil is a sort of nuisance in an office, only tolerated in consideration of the fee which accompanies him. From personal experience I can declare that most pupils are so ignorant of algebra that they are not only incapable of working out a result for themselves, but actually cannot apply the simple formulæ which are given in engineers' pocket books. The calculation of the solid contents of a wall is often beyond their powers. Their arithmetic is very shaky, and a knowledge of physics, chemistry, geology, or the higher mathematics is wonderfully rare.

Speaking generally of the British system of engineering education of that time, he said, "Our defect is the want of a good knowledge of the theories affecting our practice."

The well-known and distinguished scientific engineer, the late John Scott Russell, F.R.S., in 1869 expressed forcibly and clearly the defects at that time existing, in a lengthy *brochure* on the subject of "Systematic Technical Education for the English People." Comparing English and continental methods of actual works, he says:

> I will now come to the practical matters which show directly the results of a technical education in the production of one of its chief objects — the creation of wealth. It is notorious that most foreign railways, which have been made by themselves in the educated countries of Germany and Switzerland, have been made far cheaper than those constructed by us in England; it is known that they have been made by pupils of the industrial schools and technical colleges of these countries, and I know many of their distinguished men who take pride in saying that they owe their positions entirely to their technical schools. I find everywhere throughout their work marks of that method, order, symmetry, and absence of waste which arise from plans well thought out, the judicious application of principles, conscientious parsimony, and a high feeling of professional responsibility. In the accurate cutting of their slopes and embankments, in the careful design and thoughtful execution of their beautiful but economical stone masonry, in the self-denying economy of their large span bridges, the experienced traveller can read as he travels the work of a superiorly educated class of men; and when we come down to details, to the construction of permanent way, arrangement of signals, points and sidings, and the endless details of stations, we everywhere feel that we are in the hands of men who have spared no pains, and who have applied high professional skill to minute details.

Introducing the subject of "What Technical Education Should Be Given the Civil Engineer," he again alludes to continental methods, and pays a deserved tribute to the thorough education in France, which I have described above:

> The great public works of a civilized country have always demanded and generally received from its government earnest solicitude and forethought. In France, the civil engineers are the *élite* of the nation; the most distinguished pupils throughout the country are promoted into the central technical institution of France in Paris; and out of this again a selection is made of the most talented for the *corps de génie maritime;* for the *corps de génie militaire;* and for the *corps de génie civil*, or *ponts et chaussées.*
>
> By the great public works of a country so much is gained or lost to the public well-being, that the most liberal measures are justified if they succeed in providing for its service the profoundest knowledge, the most brilliant talent, and the highest skill.

Nine years later, 1878, speaking in his presidential address upon what great things have been accomplished in the world by the civil engineer, Mr. J. F. Bateman said:

> Still, there can be little doubt, on a review of the whole question, that our young engineers are not always prepared by preliminary education as well as they might be for their subsequent acquisition of practical knowledge. It is not because there are not institutions in this country where this knowledge can be obtained, but rather from a general laxity in the views of parents and guardians upon technical education. Special qualifications, and some of a very high order, are required to insure success in our profession, and many young men enter it as pupils without these qualifications.

Coming now to the present time, I cannot forbear the quotation here of a few brief extracts from the inaugural address, on November 3, 1898, of Sir John Wolfe Barry, president of the Institution of Civil Engineers. The whole address is worthy of the most careful reading, because, being a "jubilee" year, the president felt called upon to show what the engineering profession had accomplished in the sixty years of Queen Victoria's reign. The reading of that address would set at rest all doubts, should there be any, as to the necessity of giving civil engineers the highest and widest education possible.

I can only give here a few extracts from this admirable address, those which relate to the special subject in hand. He had just been exploding the idea that ours is the culminating epoch of the world's history by giving the increase of the world's population and the room yet for it, and remarked that we might realize the absurdity of calling

ours the culmination when we reflect that the present population of the world could stand upon the Isle of Wight:

> All these matters are of supreme interest to engineers, and reflect a strong light upon the present and future importance of our profession, which has, as I have said, advanced in so marked a manner in members, consideration, and position in the last sixty years. Without for one moment decrying the status of the able engineers who exercised their craft prior to 1837, I think it may be said that the queen's reign has, practically speaking, witnessed the birth of engineering as a profession of a most important character, and bearing, perhaps, more responsibility in respect of life and expenditure than is supported by any other calling.
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> I have enlarged upon the subject of the exploits and triumph of the engineering profession, not in a spirit of boasting, as the representative, for the time being, of a profession to which I am proud to belong, but with a view of pointing out the dignity of our calling, and the burden laid upon us thereby, as members of this great institution, of not letting that dignity suffer any loss or disparagement in years to come.
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> No profession requires more education, theoretical and practical, and more training of the mind than the profession of a civil engineer.
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> * * * * * * * *
>
> I must content myself by saying that in France, Germany, Austria, Russia, Belgium, and Holland, the greatest attention is paid by the State to a strict scientific training, and that the utmost care is taken to see that all candidates for employment as civil engineers are, so far as technical education is concerned, thoroughly equipped for the work which may lie before them.

With the following opinions I am in full accord, and I give the remarks upon the subject in full, as they might well introduce my own recommendations to follow at the close of this report. Sir John had been speaking of the requirements and examinations for admission to membership in the Institution of Civil Engineers:

> Again, as for students so for associate members, I myself am of opinion that we ought not to be content, in the case of the more advanced grade, with any low standard of general education. Of late years I rejoice that we have required examination in general education, as distinguished from scientific attainments, from intending students of the institution, and I think we may now all congratulate ourselves that this step, as to which there was some doubt, was taken. It tends distinctly to place our calling in its proper position among professions, and I hope some day to see that any intending associate member who has not entered as a student should be proved to possess at least those elements of a liberal education which we require from students, as well as technical and practical knowledge of his business. For I hold that education and instruction are not convertible terms, and that education implies that general exercise of the mind which brings out the best qualities of the human understanding and enables it to acquire and assimilate special instruction. It is somewhat like that training of the bodily powers which we call

athletics and gymnastics, fitting a man for the particular physical requirements which may in the future be laid upon him.

The education preliminary to the purely technical, which in my opinion, and I may add in the opinion of many of our best engineering educators and engineers, is necessary in these days, and which is at least suggested in the opinion of Sir John Wolfe Barry, above expressed, is more fully outlined by one of the most accomplished engineers and educators in the United States, Professor William H. Burr, professor of civil engineering in the Columbia School of Mines, New York City, who is not only experienced as an educator, but as a practical engineer.

I quote the following extracts from a paper on "The Ideal Engineering Education," read before Division E of the International Engineering Congress, held at Chicago, 1893:

> In the older learned professions this sequence of broad and general cultivation prior to, and forming the foundation of, the subsequent professional training is well defined, and the ultimate nature of the case in engineering is precisely the same as that in law or medicine. By means of a liberal training the requisite powers of observation and a sound judgment are more symmetrically developed and far more accurately applied in consequence of truer conceptions of the object on which they are brought to bear, and a correspondingly enhanced power of healthy mental assimilation is acquired. The broad cultivation, it matters little when or where it is obtained, is the only effectual corrective for that narrow and malformed excellence in some special direction, which, while it is certainly better than no excellence at all, falls lamentably short of the vigorous and well-rounded product of the ideal education in engineering. The writer unhesitatingly places, therefore, as the first and fundamental requisite in the ideal education of young engineers, a broad, liberal education in philosophy and arts, precedent to the purely professional training.
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> The complete and satisfactory discharge of such functions cannot, from their very nature, be accomplished on a bare possession of technical knowledge. This is indeed essential, but it is just as essential, and perhaps more so, to know how to use it.
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> There are, then, few professional men to whom the broadly cultivating influences of a liberal education are more needful than to the engineer. His early professional practice does not induce any development which can fill the voids of a faulty general education, while his latter practice demands what only liberal training can supply.

These views were advanced in 1893. I was desirous, for the purposes of this report, to know if the experience of the last four years had confirmed or changed these broad views of engineering education,

and I wrote to Professor Burr accordingly. While the reply is in a personal letter, I hope he will not object to my quoting directly from it, and I do so mainly for the purpose of expressing through him my own views from long study, experience, and close observation. His letter is dated February 11, 1898:

> My ideas as to engineering education have been nurtured more in active practice than in the class room. The cumulative results of observation seem to me to show with demonstrative force that the broadly educated engineer is in general the engineer who reaches the highest degree of success in the profession. He certainly has the best balanced and the most comprehensive view of large engineering problems, enabling him to reach the best results in the best way. It goes without saying that most of the successful engineers of the present day have not had a liberal education, although I believe they would have succeeded to a greater degree had they enjoyed that kind of a training. The real question now, however, is, what will the present engineer need? I believe that he, like the lawyer and the physician, already needs the broad, liberal education on which to base the technical training. His liberal education may well be trended toward that which is to follow, but it must be broad and liberal.
>
> Chiefly through my efforts, I am glad to say, Columbia has provided for the main features outlined in my paper. In the college course (four years) a student may now take civil engineering options, which shall be counted for the B.A. degree, so that at the end of his four-year college course (having taken B.A.) he can enter at the beginning of the third year in the regular civil engineering course, and two years later take the degree of C.E. This makes a six years' course in civil engineering now established, and a number of students are taking it. I am confident that we shall get excellent results from it. In our regular fourth year class of civil engineering, eighteen in number, we have three college graduates, one being from Harvard. These facts, in our own experience, seem to me to indicate clearly the kind of department now needed in engineering education. Details may, and probably will, need amplification, but the ground principles are right.

My own views on this feature of the subject I presented to the annual meeting of the Society for the Promotion of Engineering Education at Springfield, Massachusetts, in 1895, in a paper entitled, "The Civil Engineer of the Twentieth Century." In it were corroborating views of not only Professor Burr's opinions, as above quoted, but those of other men of prominence, not only engineers but of other professions. These views all accorded with those of Professor Burr as expressed above.

I may add that the observation, examination, conferences, and correspondence during the last two years, and especially during the last ten months, while engaged upon investigations in Europe, have strengthened me in my views then pronounced, and I lay it down here as a "*sine qua non*" that the engineer should be liberally and broadly educated, not

only in the technique of his work, but in the arts, the "humanities"; not necessarily in an extended linguistic course, though I believe that a fundamental knowledge of Latin and Greek and the literary discipline that the training in those languages gives are of inestimable value. Certainly a thorough knowledge of French and German and English is absolutely necessary.

You have followed my description of European education and the concurrent views of some of the engineers; you must hold with me that the thorough, liberal education of the Continent is the best to produce the highest order of professional men. I am satisfied that, if any one will examine the methods of work in all branches of engineering on the Continent, the enconiums bestowed upon them by Mr. John Scott Russell three decades ago, quoted above, remain true today. My observations, and they have been in the shape of investigations of European harbor constructions, terminal facilities, dredging appliances and methods, river rectifications, railway constructions, and canals, all show the effects of thorough education and an intelligent application of scientific principles.

I am glad to state that the tendency in the United States is constantly now towards a higher and broader education for professional engineers; mind, I am not anywhere discussing the education of mechanics or foremen, or of the ordinary helper on engineering work, but that required by professional men.

I have before me an address delivered in 1896 by Professor Mansfield Merriman, of Lehigh University, as president of the Society for the Promotion of Engineering Education.

He speaks always along those lines that tend upward, and few men have had more experience, or are more observing and studious, or have higher ideals.

It is a satisfaction to know from him that "in every university it is found that the activity and earnestness of the engineering students is a source of constant stimulus to those of other departments. Thus scientific and engineering education has tended to elevate the standard and improve the methods of all educational work."

The following, referring to a forthcoming report at the meeting where he delivered his address, will confirm the decided views of the Zürich faculty in regard to age of admission and a stringent demand for thorough and broad preliminary training:

> The report of the committee on requirements for admission, which will be presented later in the session, sets forth many facts which show the tendencies now existing. Almost without exception a higher standard is demanded, both that students may enter with better mental training, and that more time may be available in the course for technical subjects. While the general line of advance is towards an increase in mathematics and in modern languages, there is also found, particularly in the central States, a demand for broader training in science.
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> The general increase in requirements for admission tends to raise the average age of the student. It is now usually the case, owing to the greater length of time needed in preparatory work, that the average age of the classical student is one year higher than that of the engineering student, or the former has had one more year of training than the latter. One more year of training means much as an element for success; one more year in age means an increase in judgment which is of the highest importance for a proper appreciation of the work of the course. The older men in the class usually do the best, if not the most brilliant, work, and after graduation their progress is the most satisfactory. It thus appears that all tendencies that raise the age of entrance are most important ones and deserve hearty encouragement.

My own views stated above could not be more clearly or more forcibly expressed than by President Merriman in his concluding paragraph, which is so important that I quote it entire:

> Looking now forward into the future, it is seen that in our efforts for the promotion of engineering education a wide field for work still lies open. The student should enter the engineering college with a broader training and a more mature judgment. The present methods of instruction are to be rendered more thorough and more scientific. In particular, the fundamental subjects of mathematics, physics, and mechanics are to be given a wider scope, while the languages and humanities are to be so taught as to furnish that broad, general culture needed by every educated man. In general, let it be kept in mind that education is more important than engineering; for the number of men who can follow the active practice of the profession will always be limited. Hence let it be the object of engineering education to influence the world in those elements of character that the true engineer possesses, so that every graduate may enter upon the duties of life with a spirit of zeal and integrity, with a firm reliance upon scientific laws and methods, and with a courage to do his work so as best to conduce to the highest welfare of his country and of mankind.

I do not wish to trench upon the general subject of education, but it is difficult to separate engineering education from education in general, for the former will in no country ever attain its perfection until national and general methods are in full accord.

It may be the opinion in the United States and Great Britain that continental methods remain as they were many years ago; that "dead languages" and "pure theory" and "abstract science" have not per-

mitted the inroads of modern thought and discovery. Nothing could be further from the truth.

It is scarcely more than a year since the University of Paris was reëstablished in a city where subversion by modern ideas would not be thought practicable, especially as this university was simply securing a restoration to its honored place, held long before Oxford and Cambridge came into being. It was the "Mother of Universities," but was wiped out of existence in 1808 by Napoleon I. What is it to be now, this most ancient seat of learning, inaugurated by the most enlightened men of the most enlightened city? The president of the council pronounced it a practical university; no chair is to be without its laboratories; the entire establishment is to be one immense factory, adapting all branches of learning to the present great diversity of scientific truth and work.

The ideas advanced on that memorable occasion all tended distinctly, not only to specialization, but first to a thorough preparation for it by a university education.

President Gilman, of Johns Hopkins University, in a review of this inauguration, stated that, while American education is still far behindhand, there are distinct evidences "that during the next half century changes just as remarkable and just as beneficial will occur in the organization and administration of schools of every grade as those which have occurred in the last forty years, in which schools of investigation have been created with universities, colleges have introduced laboratory methods, technological institutes have been established in large cities, but all brought about without diminishing the respect that is paid to literature and history."

As to the German methods of general and special education, all will acknowledge that they are active, enthusiastic, thorough and deep, instinct with life and originality. It is these characteristics that have sent our young men to Germany ever since the close of our civil war. These methods have largely been copied — at least the inspiration came from Germany largely — by the multitude of our own people who came back enthused with the German way of teaching.

It was a revelation to those pioneers to Berlin and Heidelberg and Göttingen to find there such entirely different methods of education than existed in England and the United States, where instead of the dull routine of musty text-books, with the recitations from them presided over by the dull professor, living lectures, original research,

enthusiastic teachers with high ideals and souls earnest in creative effort and scientific discovery led the student on in earnest work. Is it a wonder that our ideas became Germanized? You will see from my brief statement of the present methods of engineering education in Germany that there has been, on these lines at least, no retrograde movement; they still lead, and the whole world knows it.

This earnestness and progressiveness pervades all branches of education, not only among the higher, but the middle and lower classes. As I have already shown, it has made its effect felt in the entire industrial world: first, of Germany, and second, wherever Germans go, and that is everywhere in the world.

We have not, unfortunately — perhaps some will say fortunately — state supervision of our education, either liberal or scientific; we have consequently wasted effort, and have come towards correct methods of education slowly, haltingly, and in a desultory and spasmodic manner. There has been division of forces and differences of opinion, and not concentrated, persistent, logical, and consistent educational methods like those of continental countries which, so far as engineering education is concerned, I have described. The following important truth was not patent to us for a long time, as expressed by a prominent educator, who said that the faults of education existing with us "might have been avoided had the people sooner realized that the quality of education in the whole state is determined by the quality of that at the top, and that the *State is responsible for its excellence.*"

Recommendations.

Though handicapped by our democratic conditions, which leaves the State out of the question and compels us by individual effort and by the munificence of individuals to accomplish what great nations undertake to do on this (European) side of the water, we ought with such an institution as the University of Chicago, founded, as it is, on correct principles and endowed with means (limited somewhat, it is true) to carry them out in practice, we ought, I say, to make no mistake; and we should learn from what is done best in the world and from how it is done to establish that kind of engineering school that will meet the wants of the higher educational aspirations of those young men in the United States who demand the best there is of educational methods

and facilities, and who will certainly go to Switzerland or Germany or France to find them if we do not ourselves furnish them.

The proper name of the school which ought to be established with the University of Chicago is the "University College of Engineering and Architecture." The fact that it is to be an integral part of the university is an immense advantage at the outset, for I think it is generally conceded that wherever such schools are connected with universities there is, other things being equal, an economy in teaching power and a tendency towards greater breadth of culture by the student mingling with those whose work lies in other fields of knowledge than his own. Another important advantage is the fact that there are already established such excellent laboratories of physics and chemistry. It should not be a part of the scheme to train foremen and mechanics; these can obtain their education and training in the manual training schools and the polytechnics, like that recently established at Peoria.

The college should be equipped, however, with practically the same laboratory facilities as those at Boston, Worcester, Sibley College at Ithaca, Zürich, and the new establishments in the German Royal Technical Colleges, or like that of the Central Technical College, London; that is, all that is necessary to teach professional engineers in civil, mechanical, electrical and mining engineering, and architecture.

I cannot go into the details of this plant, but will refer you to a paper entitled, "The Equipment of Engineering Schools," read before Division E of the International Engineering Congress in Chicago, 1893, by Professor R. E. Thurston, director of Sibley College, Cornell University. This paper gives in a few pages, in the clearest possible manner, the general requirements, particularly in respect to mechanical engineering.

I am in full accord with the entire paper; it is by an expert, so acknowledged all over the world, and his judgment cannot be for a moment questioned. He starts out with the statement that the profession of modern engineering exacts from its members "a more extended preparation, a more arduous professional course, than are commanded today by the schools of either law or medicine, and this fact, if there were no other corroboration of the conclusion, has fully established the engineer in his position as a member of a profession and of a learned profession." He then outlines the nature of the equipment, its exact adaptation for the purpose, and the general character of that required for experimental engineering.

His view is that the application of scientific methods to the solution of engineering problems promises to do more for the world than has any other systematic professional work ever yet undertaken.

This statement, and his concluding remark, I heartily endorse: "Upon the thorough education of our engineers depends very largely the future progress of the nation."

The admission requirements should be of the most advanced kind, with the intention of limiting the college to graduates of the academic colleges, or to students with equivalent training, as understood in the calendar of the university. In other words, it should be an advanced course of education, the students coming to it with such a preparation in arts and science as a degree from any good college of high standing would presuppose.

I am not expected, and do not intend, in this general report to go into details; my purpose has been mainly to exhibit, as fully as possible, the methods actually employed in various countries, from which to form an opinion as to the necessity of an engineering college and its general aims and features, its scope and methods.

You will naturally ask, after surveying the situation, as to what we already have and what we need to supply, what will be the cost of endowing such a college? I have had before me for study some information as to costs elsewhere, but not enough to go into details here; and the estimate which I made some years ago, though I think I have never stated it before, is not less than $2,000,000 for the building, or buildings, the equipment of the laboratories, the general teaching facilities, a good technical library, and to supply from the interest on the remainder of the sum the deficiency between income and expenditures.

The man, or men, who would undertake to thus endow such a college would be benefactors of the human race, and their influence would extend through such an institution to the remotest bounds of civilization, and to the United States, to its industry and commerce, the benefaction would be of inestimable value.

Rome, Italy, March 5, 1898.

Supplemental.

Since the above was written, five years have elapsed — a semi-decade of important development, educationally and otherwise, in this and other countries.

During this time I have had exceptional opportunities in this country, in Europe, and in South America, to observe and study, and my opinion is confirmed by this experience that the necessity for such a college of engineering as I have recommended is greater now than five years ago, and that it is the duty and the high privilege of the University of Chicago to establish this school.

In only one particular would I modify my views. I would double my estimate in order that the school may have all the facilities required and be unhampered in its development and usefulness; and while I would provide for the admission of students who cannot obtain a liberal education in the humanities, I would never lose sight of the main purpose of the college, which is to give a university, or professional, education.

1 Nassau Street, New York, June 5, 1903.

CONTRIBUTION FROM THE DEPARTMENT OF FOOD AND DRUG INSPECTION OF THE MASSACHUSETTS STATE BOARD OF HEALTH.

READINGS ON THE ZEISS BUTYRO-REFRACTOMETER OF EDIBLE OILS AND FATS.

BY HERMANN C. LYTHGOE.

THE Zeiss Butyro-Refractometer has been in use for a number of years for the purpose of determining the purity of butter, and it is gradually being used for other oils and fats. As the refractions of oils and fats vary with the temperature, a table giving the readings for different temperatures greatly enhances the value of the instrument.

Four such tables have been prepared and published, namely, one on butter, published by Zeiss to accompany the instrument, and one on lard by Hefelmann[1] and two by A. E. Leach,[2] on olive and cottonseed oils, respectively.

The writer has calculated tables for several other oils and fats and has incorporated them with the above mentioned tables into one table, arranging the oils and fats in the order of their refraction.

The oils of known purity used in the work were obtained from the following sources:

Expressed in the laboratory: peanut, sunflower, and lard oils, lard stearine, and mutton tallow.

Larned and Bird Oil Works, Brighton, Mass.: beef tallow, beef oleo, and beef stearine.

United States Department of Agriculture: peanut, poppyseed, rapeseed, mustard, and corn oils.

A. Colburn & Co., Philadelphia, Pa.: mustard oils.

Dr. Gill, Mass. Institute of Technology: corn oil.

Winthrop Chocolate Co.: cacao butter.

The other oils were commercial oils of undoubted purity.

[1] Pharm. Centralhalle, 1894, p. 497.

[2] Thirty-first annual report of the Mass. State Board of Health, 1899, p. 647.

The following table gives the actual readings obtained by the writer, together with the difference in reading for a variation of 1°C. in temperature, and the calculated reading at 35° C.

TABLE I.— ORIGINAL DATA.

	Scale Reading at 35°.	Difference in Reading for 1° C.	Temp. Cent.	Scale Reading.	Temp. Cent.	Scale Reading.	Temp. Cent.	Scale Reading.
Cocoanut Oil,	37.0	0.51	19.0	45.1	39.0	40.0	45.5	31.4
Beef Stearine,	47.0	0.525	. .	. .	44.0	42.4	56.0	36.1
Beef Stearine,	47.4	0.525	. .	. .	44.0	42.8	56.0	36.5
Cacao Butter,	49.1	0.541	35.0	49.1	43.5	44.5	54.5	38.9
Beef Tallow,	49.1	0.50	35.0	49.1	43.8	44.8	. .	. .
Mutton Tallow,	49.1	0.50	40.5	46.3	47.5	42.3	67.0	32.6
Lard Stearine,	50.2	0.526	35.0	50.2	62.0	36.0	. .	. .
Beef Oleo,	50.6	0.588	25.0	55.9	35.0	50.6	. .	. .
Beef Oleo,	50.7	0.588	25.0	55.9	35.0	50.7	. .	. .
Lard Oil,	54.2	0.526	16.0	64.2	28.0	58.1	35.0	54.2
Peanut Oil,	59.5	0.567	25.0	64.9	31.0	60.5	49.0	51.5
Peanut Oil,	59.8	0.547	18.0	69.1	25.5	64.6	35.0	59.8
Rapeseed Oil,	62.1	0.577	18.0	71.9	25.5	67.5	35.0	62.1
Rapeseed Oil,	62.2	. .	35.0	62.2	. .	. .	. .	. .
Yellow Mustard,	62.3	0.58	18.0	72.1	25.5	67.8	35.0	62.3
Yellow Mustard,	63.2	0.555	19.0	72.1	29.0	66.5	46.0	57.1
Black Mustard,	65.4	0.57	19.0	73.3	29.0	68.8	46.0	57.9
Black Mustard,	64.0	. .	35.0	64.0	. .	. .	. .	. .
Sunflower Oil,	64.5	0.59	14.0	76.8	35.0	64.5	65.0	47.8
Corn Oil,	65.0	. .	35.0	65.0	. .	. .	. .	. .
Corn Oil,	65.1	0.58	18.0	75.0	25.5	70.6	35.0	65.1
Corn Oil,	65.2	. .	35.0	65.2	. .	. .	. .	. .
Poppyseed Oil,	65.5	0.577	18.0	75.3	25.5	70.6	35.0	65.5

TABLE II.—Calculated Readings on Butyro-Refractometer.

Temp. C.	Cocoa-nut Oil.	Butter.[1]	Beef Stearine.	Cacao Butter.	Beef Tallow.	Lard Stearine.	Beef Oleo.	Lard.[2]	Lard Oil.
45.0	31.6	41.5	41.9	43.7	44.1	44.9	45.0	48.2	. .
44.5	31.9	41.8	42.2	44.0	44.3	45.1	45.3	48.4	. .
44.0	32.2	42.0	42.4	44.2	44.6	45.5	45.6	48.7	. .
43.5	32.4	42.3	42.6	44.5	44.8	45.7	45.9	49.0	. .
43.0	32.7	42.6	42.9	44.8	45.1	46.0	46.1	49.3	. .
42.5	32.9	42.9	43.2	45.0	45.4	46.3	46.4	49.6	. .
42.0	33.2	43.1	43.5	45.3	45.6	46.5	46.7	49.9	. .
41.5	33.5	43.4	43.7	45.6	45.8	46.8	47.0	50.1	. .
41.0	33.7	43.7	44.0	45.9	46.1	47.0	47.3	50.4	. .
40.5	34.0	43.9	44.2	46.1	46.3	47.3	47.6	50.7	. .
40.0	34.3	44.2	44.5	46.4	46.6	47.6	47.8	51.0	51.6
39.5	34.5	44.5	. .	46.6	46.8	47.8	48.1	51.3	51.8
39.0	34.8	44.8	. .	46.8	47.1	48.1	48.4	51.6	52.1
38.5	35.0	45.0	. .	47.1	47.4	48.4	48.7	51.9	52.4
38.0	35.3	45.3	. .	47.4	47.6	48.6	48.9	52.1	52.6
37.5	35.5	45.6	. .	47.6	47.8	48.9	49.2	52.4	52.8
37.0	35.8	45.9	. .	47.9	48.1	49.2	49.5	52.7	53.1
36.5	36.1	46.1	. .	48.2	48.3	49.4	49.8	53.0	53.4
36.0	36.3	46.4	. .	48.5	48.6	49.7	50.0	53.3	53.7
35.5	36.6	46.7	. .	48.7	48.8	50.0	50.3	53.6	54.0
35.0	36.9	47.0	. .	49.0	49.1	50.2	50.6	53.9	54.2
34.5	37.1	47.2	. .	. .	. .	. .	50.9	54.2	54.5
34.0	37.4	47.5	. .	. .	. .	. .	51.2	54.4	54.7
33.5	37.6	47.8	. .	. .	. .	. .	51.5	54.7	55.0
33.0	37.9	48.1	. .	. .	. .	. .	51.7	55.0	55.3
32.5	38.1	48.3	. .	. .	. .	. .	52.0	55.3	55.6
32.0	38.4	48.6	. .	. .	. .	. .	52.3	55.6	55.9
31.5	38.6	48.9	. .	. .	. .	. .	52.6	55.9	56.1
31.0	38.9	49.2	. .	. .	. .	. .	52.8	56.1	56.4
30.5	39.2	49.5	. .	. .	. .	. .	53.1	56.4	56.7
30.0	39.5	49.8	. .	. .	. .	. .	53.4	56.7	57.0
29.5	39.7	50.0	. .	. .	. .	. .	53.7	57.0	57.2
29.0	40.0	50.3	. .	. .	. .	. .	53.9	57.3	57.5
28.5	40.3	50.5	. .	. .	. .	. .	54.1	57.6	57.8
28.0	40.5	50.8	. .	. .	. .	. .	54.4	57.8	58.1
27.5	40.8	51.1	. .	. .	. .	. .	54.7	58.1	58.3
27.0	41.0	51.4	. .	. .	. .	. .	55.0	58.4	58.6
26.5	41.3	51.6	. .	. .	. .	. .	55.2	58.7	58.9
26.0	41.5	51.9	. .	. .	. .	. .	55.5	59.0	59.2
25.5	41.8	52.2	. .	. .	. .	. .	65.8	59.3	59.5
25.0	42.0	52.5	. .	. .	. .	. .	66.1	59.6	59.8

[1] Butter readings, by Zeiss.
[2] Lard readings, by Hefelmann.

TABLE II. — CALCULATED READINGS (continued).

TEMP. C.	OLIVE OIL.[1]	PEANUT OIL.	COTTON-SEED OIL.[2]	RAPE-SEED OIL.	SESAME OIL.	YELLOW MUST. OIL.	BLACK MUST. OIL.	SUN-FLOWER OIL.	CORN OIL.	POPPY-SEED OIL.
35.0	57.0	59.8	61.8	62.1	62.3	63.0	64.2	64.5	65.0	65.5
34.5	57.2	60.0	62.1	62.4	62.5	63.3	64.5	64.8	65.3	65.8
34.0	57.4	60.3	62.3	62.7	62.8	63.6	64.8	65.1	65.6	66.1
33.5	57.7	60.6	62.5	63.0	63.1	63.9	65.1	65.4	65.9	66.4
33.0	58.0	60.9	62.8	63.3	63.4	64.1	65.3	65.7	66.2	66.7
32.5	58.3	61.1	63.0	63.6	63.7	64.4	65.6	66.0	66.5	67.0
32.0	58.5	61.4	63.2	63.8	64.0	64.7	75.9	66.3	66.8	67.3
31.5	59.0	61.7	63.6	64.1	64.3	65.0	66.2	66.6	67.1	67.6
31.0	59.2	62.0	64.0	64.4	64.6	65.3	66.5	66.9	67.4	67.9
30.5	59.5	62.2	64.2	64.7	64.9	65.6	66.8	67.2	67.7	68.2
30.0	59.9	62.5	64.5	65.0	65.1	65.8	67.0	67.5	68.0	68.5
29.5	60.1	62.8	64.9	65.3	65.4	66.1	67.3	67.7	68.2	68.7
29.0	60.3	63.1	65.1	65.6	65.7	66.4	67.6	68.0	68.5	69.0
28.5	60.6	63.3	65.3	65.9	66.0	66.7	67.9	68.3	68.8	69.3
28.0	60.9	63.6	65.7	66.1	66.2	66.9	68.1	68.6	69.1	69.6
27.5	61.1	63.9	66.0	66.4	66.5	67.2	68.4	68.9	69.4	69.9
27.0	61.5	64.2	66.5	66.7	66.8	67.5	68.7	69.2	69.7	70.2
26.5	62.0	64.4	67.0	67.0	67.1	67.8	69.0	69.5	70.0	70.5
26.0	62.2	64.7	67.3	66.3	67.4	68.0	69.2	69.8	70.3	70.8
25.5	62.4	65.0	67.5	67.6	67.7	68.3	69.5	70.1	70.6	71.1
25.0	63.0	65.3	67.9	67.8	67.9	68.6	69.8	70.4	70.9	71.4
24.5	63.3	65.5	68.2	68.1	68.2	68.9	70.1	70.7	71.2	71.7
24.0	63.6	65.8	68.5	68.4	68.5	69.2	70.4	71.0	71.5	72.0
23.5	63.9	66.1	68.8	68.7	68.8	69.5	70.7	71.3	71.8	72.3
23.0	64.2	66.4	69.1	69.0	69.1	69.7	70.9	71.6	72.1	72.6
22.5	64.5	66.6	69.4	69.3	69.4	70.0	71.2	71.9	72.4	72.9
22.0	64.8	66.9	69.7	69.7	69.7	70.3	71.5	72.2	72.7	73.2
21.5	65.1	67.1	70.0	70.0	70.0	70.6	71.8	72.5	73.0	73.5
21.0	65.4	67.4	70.3	70.3	70.3	70.9	72.1	72.8	73.3	73.8
20.5	65.7	67.7	70.6	70.6	70.5	71.2	72.4	73.1	73.6	74.1
20.0	66.0	68.0	70.9	70.8	70.8	71.4	72.6	73.4	73.9	74.4
19.5	66.3	68.2	71.2	71.1	71.1	71.7	72.9	73.6	74.1	74.6
19.0	66.6	68.5	71.5	71.4	71.4	72.0	73.2	73.9	74.4	74.9
18.5	66.9	68.8	71.8	71.7	71.7	72.3	73.5	74.2	74.7	75.2
18.0	67.2	69.1	72.1	72.0	72.0	72.6	73.8	74.5	75.0	75.5
17.5	67.5	69.3	72.4	72.3	72.3	72.9	74.1	74.8	75.3	75.8
17.0	67.8	69.6	72.7	72.6	72.5	73.1	74.3	75.1	75.6	76.1
16.5	68.1	69.9	73.0	72.9	72.8	73.4	74.6	75.4	75.9	76.4
16.0	68.4	70.2	73.3	73.2	73.1	73.7	74.9	75.7	76.2	76.7
15.5	68.7	70.5	73.6	73.5	73.4	74.0	75.2	76.0	76.5	77.0
15.0	68.9	70.8	73.8	73.8	73.7	74.3	75.5	76.3	76.8	77.3

[1] Olive oil readings, by A. E. Leach.
[2] Cottonseed oil readings, by A. E. Leach.

The refraction of beef stearine could not be read at 35° as it melts at a higher temperature, but its refraction has been calculated to 35° for convenience in comparison. These figures agree very closely with figures of other writers, except in the case of peanut oil, in which a marked difference occurs. Lewkowitsch[1] gives the reading at 25° as 66–67.5, in the neighborhood of cottonseed oil, while Utz[2] gives it at the same temperature as 63.2, in the neighborhood of olive oil.

The writer found three samples of peanut oil of known purity to read 64.9, 65.0 and 65.3, respectively, at a temperature of 25° C., and it is from these oils that the readings for Table II have been calculated.

In Table II the readings of the solid fats are given from 25°, or from the melting points if above this, to 45°, and the liquid oils are given from 15° to 35° C.

The constants of a few of the oils are as follows:

TABLE III.—CONSTANTS FOR CERTAIN OILS.

	BUTYRO-REF. AT 35°.	IODINE NUMBER.	SPEC. GRAV.
Beef Stearine,	47.0 (calculated)	27.17	0.9510
Lard Stearine,	50.2	43.49	0.9496
Beef Oleo,	50.6	50.67	0.9256
Lard Oil,	54.2	70.04	0.9146

[1] Fats, oils and waxes.

[2] Apoth. Zeit, 1900, 15, p. 651; Abstract in Zeit. Unters, Nahr und Genuss, 1901, p. 453.

THE SIGNIFICANCE OF BACTERIOLOGICAL METHODS IN SANITARY WATER ANALYSIS.

By C.-E. A. WINSLOW and C. P. NIBECKER.

1. *Sanitary Inspection and Its Limitations.* — It is well recognized today that a study of the possible sources of pollution on a watershed, of the direction and velocity of currents above and below ground, of the character of soil and the liability to contamination by surface wash, may furnish the expert with evidence of the greatest value. Often, however, he must form some opinion upon the quality of water sent from a distance without the opportunity of examining its surroundings; and even when a sanitary inspection can be made its results are by no means conclusive. No reconnoissance can show certainly whether unpurified drainage from a cesspool does or does not reach a given well; whether sewage discharged into a lake does or does not find its way to a neighboring intake; whether pollution of a stream has or has not been removed by a certain period of flow. Evidence upon these points must be obtained from a careful study of the characteristics of the water in question, and this study can be carried out along two lines, chemical and bacteriological.

2. *The Significance of the Chemical Analysis.* — A chemical examination of water for sanitary purposes is mainly useful in throwing light upon one point — the amount of decomposing organic matter present. Humus-like substances may be abundant in surface waters quite free from harmful pollution, but these are stable compounds. Easily decomposable bodies, on the other hand, must obviously have been recently introduced into the water, and mark a transitional state. "The state of change is the state of danger," as Dr. T. M. Drown has phrased it. Sometimes the organic matter has been washed in by rain from the surface of the ground; sometimes it has been introduced in the concentrated form of sewage. In any case, it is a warning of possible pollution, and the determination of free ammonia, nitrites, carbonaceous matter as shown by "oxygen consumed," and dissolved oxygen yield important evidence as to the sanitary quality of a water.

Furthermore, nitrates, the final products of the oxidation of organic matter, and the chlorine introduced as common salt into all water which has been in contact with the wastes of human life, furnish additional information as to the antecedents of a sample. The results of the chlorine determination are indeed perhaps more clear than those of any other sanitary process, for chlorine and sewage pollution vary together, due allowance being made for the proximity of the sea and other geological and meteorological factors. Unfortunately, it is only past history and not present conditions which these latter tests reveal, for in a ground water completely purified, from a sanitary standpoint, such soluble constituents remain, of course, unchanged. Thus, in the last resort, it is upon the presence and amount of decomposing organic matter in the water studied that the opinion of the chemist must be based.

3. *The Quantitative Bacteriological Examination of Water.* — The decomposition of organic matter may be measured either by the material decomposed or by the number of organisms engaged in carrying out the process of decomposition. The latter method has the advantage of far greater delicacy, since the bacteria respond by enormous multiplication to a very slight increase in their food supply, and this fact, which necessitates great care in methods and great caution in the interpretation of results, has led hasty observers to condemn the quantitative bacteriological methods. The past ten years have witnessed, however, remarkable progress, and the establishment of a procedure for the making of approximately uniform media, through the efforts of G. W. Fuller, G. C. Whipple and other prominent members of the American Public Health Association, has placed quantitative bacteriology on a reasonably firm basis.

The distinction between quantitative and qualitative bacteriological analysis is a somewhat arbitrary one. The gelatin plate is not only quantitative but also qualitative, inasmuch as it eliminates numerous bacteria for whose growth its conditions are unfavorable, and the dextrose broth tube is a quantitative as well as a qualitative test when it is applied to a series of measured portions of the water to be examined. A better classification would separate processes which indicate decomposing organic matter in general from those other methods which aim at the separation of the organisms associated more specifically with sewage pollution. Under the first head comes only the standard gelatin plate count at 20°; and this count, as above suggested, roughly

corresponds, in not too heavily polluted waters, to the free ammonia and "oxygen consumed," as revealed by chemical analysis. If low numbers of bacteria are found, the evidence is highly reassuring, for it is seldom that water could be contaminated under natural conditions without the direct addition of foreign bacteria or of organic matter which would induce a rapid multiplication of those already present. The bacteriologist, in such cases, can declare the innocence of the water with justifiable certainty. Recently an examination was made by one of us of a town supply which was derived from a filter gallery on the shore of a lake below a gathering ground occupied by a considerable population. Public confidence in this water had been shaken because the chlorine was high, about eight parts per million. It is true that the ammonias were fairly low, the free ammonia being about .03 parts and the albuminoid ammonia about .05 parts per million; but the gelatin count proved far more instructive. Plates made from water taken at different parts of the system showed from 0 to 5 colonies per cubic centimeter, indicating, in connection with sterile litmus-lactose-agar plates at 37° and negative tests for *Bacillus coli*, that at the time of examination all pollution had, without question, been effectually removed. Only repeated studies could, of course, prove this condition to be permanent, but the same objection applies to any other method of analysis.

If the gelatin count be high, the interpretation is less simple. In the first place, high numbers are at times due to the exceptional multiplication of certain water forms, which may generally be detected by inspection of the plates. Thus a sample of spring water recently received from a distance contained, on arrival, 4,200 bacteria per cubic centimeter, almost all the colonies being those of the fluorescent water bacillus. Sterile litmus-lactose-agar plates and negative tests for sewage bacteria confirmed the conclusion that in this case the high count signified only a multiplication in transit. Large numbers, under ordinary conditions, when they include a normal variety of forms, indicate, however, the presence of an excess of organic matter. Such organic matter may not mean sewage pollution; it does mean at least the presence of washings from the surface of the ground, which always implies the possibility of pollution; and no supplies exposed to such conditions are now considered satisfactory. The close correspondence between the excess of bacteria in surface waters during the winter and spring months, and the epidemics of typhoid fever due

to the same waters, brings out forcibly the reality of this danger, and emphasizes the fact that high total numbers of bacteria are always to be regarded as possibly significant.

4. *The Isolation of Intestinal Bacteria.* — The bacteriologist can, however, do more than detect the presence of general organic contamination; he can discover as well in polluted water certain semi-parasitic organisms, found in large numbers in the alimentary canal, whose presence specifically indicates the entrance of sewage. Ever since its interference with the early attempts to isolate the germ of typhoid fever from water the *Bacillus coli* has been recognized as an organism of this character, and in recent years the researches of the English sanitarians, A. C. Houston, E. Klein, and W. H. Horrocks, have shown the importance of the streptococci in the same connection.

This whole subject is a new one, and even in the technique of the colon test divergent opinions still exist on two points, which, it is to be hoped, may be harmonized for the sake of comparability. In the first place, the tests used in defining *Bacillus coli* are not yet quite uniform. For example, Whipple has recently[1] given forty-eight hours as the period for the nitrate, milk, and indol reactions; while twenty-four hours is the time employed in many laboratories for the two first, and seventy-two hours for the last of these tests. Whipple also includes the failure to form spores as one of the routine tests for *Bacillus coli*, which seems to us needless, as there are no forms likely to be found in water analyses which form spores while giving all the other reactions of the organism. These slight differences in method do not, however, materially affect the practical results of the colon test. The main characteristics of the bacillus, the typical reactions on agar and gelatin, and in dextrose broth, milk, nitrate solution, and peptone solution, are well understood; and the effect of the different periods used for the tests will only be manifest in the inclusion or exclusion of certain allied forms, which Whipple assumes, with some probability, to be typical colon bacilli, weakened by sojourn under unfavorable conditions. It seems to us desirable, in the present state of our knowledge, to exclude, as far as possible, these atypical forms, whose significance is still uncertain.

More serious than slight variations in the technique of the colon test is the failure to apply it quantitatively to the examination of small samples of water, cubic centimeters or fractional parts. *Bacillus coli* has frequently been found in large samples of waters of fair sanitary

quality. Prescott[2] has shown the identity of this organism with certain lactic acid bacteria found upon grains and other cereals. Whipple remarks that, "*Bacillus coli*, if not widely distributed in nature, resembles certain common bacteria in all points covered by the usual tests;" but it by no means follows, as he states, that this throws "doubt upon the use of this organism as a conclusive test for fæcal contamination." Many German bacteriologists, particularly the pupils of Kruse, at Bonn, have indeed concluded, because they could isolate colon bacilli from good waters by the examination of a series of liter samples, that the test was valueless. It is essentially, however, a question of less and more. Colon bacilli are either wanting in good waters or are so rare as not to be found in the examination of samples of one cubic centimeter; they are found in a majority of one cubic centimeter samples of water so polluted as to be dangerous for drinking; between these two extremes their numbers vary with the amount of pollution. Klein and Houston[3] in England, Jordan,[4] and Winslow and Hunnewell[5] in America, and very recently, Petruschky and Pusch[7] in Germany, have exhaustively studied the distribution of the colon bacillus with uniform results. That the absence of this organism demonstrates the harmlessness of a water as far as bacteriology can prove it no one would probably hesitate to acknowledge; and that, when present, its numbers form a trustworthy measure of its sanitary condition, the observers above quoted have proved beyond reasonable cavil.

5. *The Fermentation Test.* — In a thorough examination of a single sample of water the attempt should be made to isolate colon bacilli and streptococci, and to work them out in detail. Often, however, when a quick result is desired, or when a long series of routine observations must be made, some shorter method is desirable. The classic work of Theobald Smith early pointed out that the dextrose broth tube furnished such a rapid test,[6] and it has since been well established that organisms found in water which at 37° produce in twenty-four hours a good quantity of gas, made up of approximately two parts of hydrogen to one part of carbon dioxide, are almost always colon bacilli. In the paper to which reference has several times been made, Whipple[1] has brought strong evidence of the value of this, which he calls the "presumptive test" for *Bacillus coli*. The diagrams there given, showing the chemical and bacteriological relation of certain surface waters grouped under six headings, according to their relative pollution as determined by inspection, are striking, and indicate that the presump-

tive colon test harmonizes closely with actual conditions. Whipple's scale, according to which water giving a positive presumptive test in one cubic centimeter is questionable and in one-tenth of a cubic centimeter is probably unsafe, seems justified by all the evidence at hand.

6. *The Litmus-Lactose-Agar Plate.* — Besides the gelatin plate count at 20° and the study of dextrose broth tubes, either with determination of the gas formula alone or with sub-cultures definitely to identify the colon bacillus and the streptococci, there is another method of examination — the direct plating of the water in litmus-lactose-agar, — which has never come into such general use, but which is capable of wide and helpful application. Hazen and White,[8] as long ago as 1891, suggested that agar plates grown at the body temperature, instead of permitting the growth of all the water species, would "present a selected number, namely, those which can live at blood heat; including, we may believe, most of the parasitic and pathogenic germs, which, under the circumstances, are the ones of greatest interest; and eliminating those species which cannot grow at the temperature of the body, and are, therefore, in most cases, as such, presumably harmless."

In 1893, Mathews,[9] now so widely known for his physiological researches, published in this journal an account of the Wurtz litmus-lactose-agar plate, introduced into this country in the previous year by Professor Sedgwick and himself, and suggested its application to the sanitary analysis of water. Fifty-nine samples of water examined gave results summarized in the following table, indicating clearly what the author described as a "heat and agar differentiation."

Sources of Water.	Average Number of Colonies per c.c.	
	Gelatin 20°.	Wurtz-Agar 37.5°.
Wells, springs	1,664	28
Reservoirs	153	43
Ponds	296	95
Taps	242	24
Streams	273	101

The main object of this work was to facilitate isolation of the typhoid bacillus from water by eliminating those forms likely to mask it

on the gelatin plate. It was obvious, however, that a method giving such special prominence to organisms growing at the body temperature and to the acid formers, which have more and more come to be recognized as intestinal forms, must have a direct application to sanitary water analysis.

The general interest awakened about 1893 by the colon test perhaps accounts for the fact that the agar plate method was used less for its own sake than as an aid in the separation of *Bacillus coli*. It has been extensively applied to this purpose by the Massachusetts State Board of Health; in 1899 the average number of colon bacilli in the Merrimac River water thus determined varied from eight per c.c. in August to 140 in December.[10] Irons,[11] at about the same time, compared the method with the dextrose broth tube for the isolation of *Bacillus coli*, and concluded that it was less useful than the latter, especially when applied to highly polluted waters.

English sanitarians have made good use of this test, modified by the addition of one-thousandth part of phenol to the litmus-lactose-agar medium. The elaborate researches of Chick,[12] for example, showed 6,100 colon bacilli per c.c. in the Manchester Ship Canal, 55–190 in the polluted River Severn, and numbers up to 65,000 per gram in roadside mud. On the other hand, of thirty-eight unpolluted streams and rivulets, thirty-one gave no *Bacillus coli*, and the other seven gave one per cubic centimeter or less. The Liverpool tap water, snow, rain, and hail gave no colon bacilli.

Few recent authors appear to have used the 37° count and the count of acid formers as in themselves important, although Rideal[13] lays some stress upon the former and mentions that a London water gave on an average only one-twelfth as many colonies on agar at 37° as on gelatin at 20°. The blood temperature count has, however, been in constant use in the biological laboratories of the Massachusetts Institute of Technology, at the University of Chicago, at Beloit College and some other institutions, and in legal practice, with results of uniform significance.

7. *New Studies of Unpolluted Waters by means of the Litmus-Lactose-Agar Plate.* — We are strongly of the opinion that this feature of the bacteriological analysis should not be neglected, particularly in view of the fact that the litmus-lactose plate reveals the presence of the streptococci which may be overlooked in the dextrose tube. Because of the small attention paid to the method in recent text-books and the

paucity of published data as to its results, we have thought it worth while to repeat Mathews's work of 1893 by the examination of 259 samples of water. The samples covered as wide a range as possible of waters presumably not polluted by sewage, our object being to show definitely whether organisms growing at 37° and fermenting sugar are rare in such sources. Besides the public supplies of thirteen cities and towns, we examined waters from brooks, ponds, springs, deep and shallow wells, swamps, and pools in fields and woods. The samples were collected between January and May of 1903, and in some instances the spring rains had washed excessive amounts of organic matter into the waters tested. In most cases the samples were brought to the laboratory within four to six hours, and two gelatin plates, two litmus-lactose-agar plates, and three dextrose broth tubes were inoculated from each, one cubic centimeter portions being used, or one-tenth of a cubic centimeter portions in plating from those samples which contained an obvious excess of organic matter. The agar plates were counted after twenty-four hours at 37°, the number of red colonies being noted, and at the same time the dextrose broth tubes were examined and the gas formula determined. The gelatin plates were counted after forty-eight hours.

8. *Results of Our Studies.* — The results of the examination are shown in detail upon the accompanying table. The gelatin counts, it will be noted, ranged high in some cases: the Dedham, Medford, and Milton supplies, the Sharon well, the roadside pools, and the drainage from a pasture giving figures which would excite suspicion. The high Milton figures may probably be explained by the fact that these samples were two to three days old when examined, a condition which obtained in no other case. The Dedham average was due to very high counts on two samples, the other plates being sterile.

The total count on litmus-lactose-agar was, in general, low, the highest average being 46 for the Sharon well and 31 for the pools in the fields. The general average for the whole 259 samples was less than 8. Colonies of strong red color were found in only two samples, one from the Sharon well and one from the Brookline supply. In the latter case, we have reason to suspect contamination after the collection of the sample and while it was out of our hands. A very faint acid producer, giving a mere suggestion of red color, was present in a number of the public supplies, and proved to be *Bacillus mycoides*, or a closely related form. Finally, of the dextrose broth tubes

EXAMINATION OF 259 SAMPLES OF WATER FROM APPARENTLY UNPOLLUTED SOURCES.

Source of Samples.	Number of Samples.	Gelatin Plates.				Litmus-Lactose-Agar Plates.					Dextrose Broth Tubes.			
		Number of plates.	Maximum number of colonies.	Minimum number of colonies.	Average number of colonies.	Number of plates.	Maximum number of colonies.	Minimum number of colonies.	Average number of colonies.	Plates showing red colonies.	Number of tubes.	Number of tubes with gas.	Number of tubes with gas 1-0.	Number of tubes with gas 2-1.
Cambridge supply (tap).	5	10	240	20	94	8	15	2	11	0	15	0	0	0
Wakefield and Stoneham supply (tap).	7	14	150	20	59	13	12	2	6	0	21	0	0	0
Lynn supply (tap).	6	12	20	0	16	12	6	1	3	0	18	0	0	0
Brookline supply (tap).	1	2		all liquefied		2	21	15	18	2	3	0	0	0
Plymouth supply (tap).	6	12	70	10	35	12	6	0	2	0	18	0	0	0
Peabody supply (tap).	3	6	261	30	141	5	36	1	21	0	9	2	2	0
Dedham supply (tap).	6	12	13,500	0	3,717	11	3	0	1	0	18	0	0	0
Newburyport supply (tap).	6	12	100	10	36	12	14	2	9	0	18	0	0	0
Salem supply (tap).	5	10	267	200	232	10	23	10	14	0	15	0	0	0
Taunton supply (tap).	4	7	41	10	13	8	5	0	2	0	12	0	0	0
Sharon (well) (tap).	3	6	845	630	738	6	74	30	46	2	9	3	0	3
Medford supply (tap).	5	10	1,250	240	524	10	16	3	8	0	15	0	0	0
Milton supply (tap).	2	4	5,000	4,200	4,700	4	0	0	0	0	6	0	0	0
Westerly, R. I., supply (tap).	1	2		all liquefied		2	13	12	12	0	3	0	0	0
Brooks.	61	122	1,010	30	223	121	83	0	7	0	183	13	13	0
Driven wells.	15	30	54	0	18	30	5	0	1	0	45	0	0	0
Springs.	32	64	1,270	20	294	64	13	0	2	0	95	13	13	0
Ponds fed by brooks.	15	30	340	100	167	30	24	0	9	0	45	1	1	0
Melted snow.	1	2		all liquefied		2	5	3	4	0	3	0	0	0
Pools in fields.	22	44	760	100	365	44	95	2	31	0	66	2	2	0
Pools in woods.	22	44	580	10	181	43	14	0	3	0	65	0	0	0
Roadside pools.	10	20	9,000	410	811	20	10	0	4	0	30	2	2	0
Stream, Blue Hill Reservation.	1	2		all liquefied		2	0	0	0	0	3	0	0	0
Flow from rocks.	2	4	60	30	47	4	2	0	0	0	6	0	0	0
Ponds fed by springs.	6	12	420	60	188	12	5	0	2	0	18	0	0	0
Drainage from manured pasture.	1	2	1,270	1,200	1,235	2	28	26	27	0	3	0	0	0
Swamps.	3	6	310	240	269	6	10	0	6	0	9	5	5	0
Rain water, after twelve hours' heavy fall.	7	14		all liquefied		14	6	0	2	0	21	0	0	0
Shallow well in Lynn Woods.	1	2	20	10	15	2	1	1	1	0	3	0	0	0
Totals,	259	517				511				4	775	41	38	3

inoculated, only forty-one showed gas, and of these, only three, made from the Sharon well, gave the proper gas formula. The organism here actually proved to be *Bacillus coli;* and as the well is situated just below a stable and barnyard we are inclined to believe it actually polluted. Thus this apparent exception only adds to the force of the general rule.

If we consider the results of this examination of the litmus-lactose-agar plate it becomes apparent that organisms capable of growth at the body temperature are not numerous in unpolluted waters; acid formers are practically absent.

We have made no special comparative examinations of polluted waters because their condition is fairly well known. The Massachusetts State Board of Health results, and those obtained by Chick for *Bacillus coli* alone, are sufficiently large to give an idea of the number of acid formers present in polluted streams; while in some recent work at the Institute, to be published shortly, Mr. S. K. Baker has found total 37° counts ranging from 9,800 to 16,900 in water from various parts of the Charles River. Two twenty-four-hour examinations of Boston sewage, made at the Sanitary Research Laboratory of the Massachusetts Institute of Technology during the summer of 1903, gave an average of 3,660,000 bacteria per c.c. on gelatin at 20°, and 2,310,000 bacteria per c.c. on lactose-agar at 37°, with 550,000 acid formers. In general, we may say that the total count on litmus-lactose-agar will be likely to run into hundreds in polluted waters, sometimes equalling that obtained on gelatin at 20°, with a large proportion of acid formers; while good waters will show a count under fifty, with acid formers only rarely present. From exceptionally pure waters sterile plates at 37° may often be obtained.

9. *Summary of Bacteriological Methods.* — In conclusion, it appears, in the light of present knowledge, that the full bacteriological examination of the future will consist of three parts — the gelatin plate count as an estimate of the amount of organic decomposition in process; the total count and the count of red colonies on litmus-lactose-agar, as a measure of the organisms which form acids and thrive at the body temperature; and the study of a series of dextrose broth tubes for the isolation of colon bacilli and streptococci. The simple examination of the dextrose broth tube and the count on the litmus-lactose-agar plate will serve for what Whipple has well called presumptive tests.

10. *Significance of Bacteriological Results.* — The results of the bacteriological examination have, in several respects, a peculiar and unique significance. First, this examination is the most direct hygienic method of water analysis. Whipple,[1] in the paper quoted above, says that his presumptive test "gives results that agree well with chemical and biological analysis." Bacteriology, however, needs no such indirect justification. What we dread in drinking water is the presence of pathogenic bacteria, mainly from the intestinal tract of man, and it is quite certain that the related non-pathogenic bacteria from the same source will reveal the presence of these disease germs more clearly than will any chemical compounds. In the second place, the bacteriological methods are far more delicate than any others. Klein[3] showed by experiment with dilutions of sewage that the colon test was from ten to one hundred times as sensitive as the methods of chemical analysis; and a simple calculation shows that this must be the case, since sewage contains only from a hundred to a thousand times as much chlorine as good drinking water against ten thousand to a hundred thousand times as many colon bacilli. Studies of the self-purification of streams have confirmed these conclusions on a practical scale. Thus in the Sudbury River it was found that while the chemical evidences of pollution persisted for six miles beyond the point of entrance, the bacteria introduced could be detected for four miles further.[14] Thirdly, negative tests for *Bacillus coli* and low bacterial counts may be interpreted as proofs of the good quality of water, with a certainty not attainable by any other method of analysis. Many a surface water with reasonably low chlorine and ammonias has caused epidemics of typhoid fever; but it is impossible, under any natural conditions, that a water could contain important typhoid contamination without giving clear evidence of pollution in the dextrose broth tube or on the lactose-agar plate.

It seems to the writers that the real application of chemistry begins where that of bacteriology ends. When pollution is so gross that its existence is obvious and only its amount needs to be determined, the bacteriological tests will not serve on account of their excessive delicacy. In studying the heavy pollution of small streams, the treatment of trades wastes, and the purification of sewage, the relations of nitrogenous compounds and of oxygen compounds are of prime importance. In other words, when pollution is to be avoided because the decomposition of chemical substances causes a nuisance, it must be studied by chemical methods. When the danger is of infection and comes

only from the presence of bacteria, bacteriological methods furnish the best index of pollution.

In the study of certain special problems the paramount importance of bacteriology is generally recognized. The distribution of sewage in large bodies of water into which it has been discharged may be traced best in this way on account of the ready response of the bacterial counts to slight proportions of sewage, particularly since the ease and rapidity with which the technique of plating can be carried out make it possible to examine a large series of samples with a minimum of time and trouble. For the same reasons, and because the factors which condition the disappearance of disease germs from a polluted river must operate most nearly in the same manner upon related parasitic forms, the fermentation tube and the gelatin and lactose-agar plates furnish the best criteria for a study of the self-purification of streams. Finally, the quickness with which slight changes in the character of a water are marked by fluctuations in bacterial numbers renders the bacteriological methods invaluable for the daily supervision of surface supplies or of the effluents from municipal filtration plants.

In the commoner case, when normal values obtained by such routine analyses are not at hand, the problem of the interpretation of any sanitary analysis is a more difficult one. The conditions which surround a source of water supply may be constantly changing. No engineer can measure the flow of a stream in July and deduce the amount of water which will pass in February. Yet the July gauging has its own value and significance. So a single analysis of any sort is not sufficient for all past and future time. If it gives a correct picture of the hygienic condition of the water at the moment of examination, it has fulfilled its task; and this the bacteriological analysis can do. The evidence furnished by inspection and by chemical analysis must be welcomed whenever it can be obtained. Yet we are of the opinion that, on account of their directness, their delicacy, and their certainty, the bacteriological methods should be the last to be omitted, and, if necessary, they alone may furnish conclusive testimony as to the safety of a potable water.

In conclusion, we desire to express our thanks to Professor W. T. Sedgwick, whose interest in this subject has been our chief inspiration, as it was that of some of its earliest investigators in 1891 and 1893.

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STRUCTURE AND COMPOSITION OF THE DELTA PLAINS FORMED DURING THE CLINTON STAGE IN THE GLACIAL LAKE OF THE NASHUA VALLEY.[1]

By W. O. CROSBY.

Introduction.

During the Clinton stage of Lake Nashua the impounded waters found an outlet through the pass in the eastern wall of the valley now occupied by the Central Massachusetts Railroad and later to be closed by the South Dike (one of the auxiliary dams of the Wachusett Reservoir), and were probably tributary to the Charles River and Massachusetts Bay, as described in the preceding paper.[2] The normal elevation of this outlet is about 370 feet, or about 70 feet lower than the outlet southward into Lake Quinsigamond and the Blackstone River during the earlier, Boylston, stage. Since the South Dike pass is the lowest point in the rim of the Nashua Valley south of Ayer Junction and the Fitchburg Railroad, more than a dozen miles to the northward, we may fairly assume that the Clinton stage of Lake Nashua was the longest in its history. Certainly in no other part of the valley have the delta plains a more perfect or more continuous development. As

[1] This paper will complete the series of contributions to the geology of the Nashua Valley, in Massachusetts, based upon the studies and observations made by the writer in connection with the operations of the Metropolitan Water Board in the construction of the Wachusett Reservoir and Aqueduct. The first paper, on the "Geology of the Wachusett Dam and Wachusett Aqueduct Tunnel" (Technology Quarterly, Vol. XII, 68–96), relates especially to the character and structural relations of the rock formations of a limited portion of the eastern side of the valley; the second paper, on the "Geological History of the Nashua Valley during the Tertiary and Quaternary Periods" (Technology Quarterly, Vol. XII, 288–324), is essentially a physiographic study of the region, considering especially the history of the drainage and the successive stages of glacial Lake Nashua; and the purpose of this third paper is a detailed account of some of the deposits formed during a single stage of Lake Nashua. Once more I feel myself deeply indebted to the Metropolitan Water Board for the opportunity to do this work and for permission to publish the results of scientific interest, and my grateful acknowledgments are also due the chief engineer of the board, Mr. F. P. Stearns, and various members of his staff for many special facilities and helpful courtesies in the prosecution of the work.

[2] Technology Quarterly, **12**, 318.

previously noted,[1] however, the plains of this stage belong almost wholly to its earliest phase, when the water area was small, occurring chiefly in Boylston and Clinton and almost wholly south of Lancaster, suggesting that over the long stretch of the valley between Clinton and Ayer the ice margin retreated too rapidly to permit the formation of extensive plains of normal height in water from 100 to 200 feet deep. Although, as the accompanying map shows, the Clinton plains, with normal elevations of 375 to 385 feet, are broadly and typically developed in the districts both immediately northwest and southwest of the village of Clinton, it is in the latter area that they have been most perfectly exposed for study by deforesting, and most fully explored, first, by drilling, preparatory to the construction of the North Dike, and second, by the excavation of the great trench subsequently filled with impervious material to form the core, or cut-off, of the dike. The main cut-off trench afforded a nearly continuous section, having an aggregate length of 9,556 feet and a maximum depth of 60 feet, and in addition to this there was a shorter secondary cut-off trench. The wash-drill borings, to the number of 1,131, with an average depth of 83 feet and a maximum depth of nearly 300 feet, are distributed systematically and somewhat uniformly over an area 9,000 feet in length (east-west) and 2,000 to 3,000 feet in breadth. Nearly 10,000 samples from these borings have been examined, in part somewhat exhaustively, and it is, perhaps, within bounds to say that in certain aspects no similar body of modified drift has been more thoroughly investigated. The available data seem, therefore, to justify a somewhat elaborate description and discussion — especially when taken in connection with the fact, fully brought out by the borings, that these delta deposits fill and deeply bury the preglacial gorge of the Nashua River and have thus, for this region, very exceptional thickness; and the further fact that externally, also, they are rather impressive examples of the type, presenting ideal developments of all the normal features, including ice contact, frontal and erosion slopes, and the plain upper or top-set surface dimpled by kettles. Moreover, tributary eskers are not wholly wanting, notwithstanding the great average depth of the water in which the deltas were built.

The plan of this paper embraces, then, a brief account of the external and formal features of the Clinton deltas, followed by the more

[1] Technology Quarterly, **12**, 323.

minute and elaborate description and discussion of structure and composition indicated in the title; and its publication is not lacking in timeliness, since the borings and excavations are completed, while the natural contours of a large area have been effaced by the building of the North Dike, and all that part of the deltas south of the North Dike will be permanently submerged within the next five years by the filling of the great reservoir.

Formal Features of the Clinton Plains.

Recessional Development and Original Subdivision. — Narrow marginal developments, mainly erosion remnants of plains coinciding in elevation with the Clinton delta, terrace the Nashua Valley as far up as Oakdale, where the Nashua is formed by the confluence of the Stillwater and Quinepoxet Rivers. Each of the marginal developments promptly rises above the Clinton level. It is probable, however, that these are not to any important extent the product of free delta growth at this level, but they may be ascribed in the main, if not wholly, to the erosive action of the river as it cut down through the plains of the preceding, or Boylston, stage and developed its flood plains at the base level determined by the South Dike or Clinton outlet of Lake Nashua, as described in an earlier paper.[1] In other words, during the Boylston stage the entire valley above the ice margin, which was then in the latitude of Boylston (Sawyer's Mills), was probably, except where occupied by residuary masses of ice, completely filled by the Boylston deposits to the level of that stage (440 feet), leaving no room south of the Boylston ice margin for the extension of the later Clinton plains. And with the opening of the South Dike pass came a rapid development of the Clinton plain, made possible by the necessarily rapid erosion of the high and deep deposits of the Boylston stage. In fact, the waste of the Boylston plain along the axis of the valley must have been enormous in the first few years after it became exposed to the rush of the Nashua and its tributaries, with a fall of from 10 to 20 feet per mile, and we cannot escape the conclusion that through the coöperation of the Nashua with the glacial streams from the northward the Clinton plain was developed continuously along the southern margin of the ice to the outlet, the level of

[1] Technology Quarterly, 12, 320.

Washaccum Ponds
Stillwater River
Sterling Junction
Quinapoxet River
Outlet
Flow Line of the Res. Outlet
Boylston Common
West Boylston
Flow Line of the Reservoir
NASHUA RIVER
Probable Buried Gorge
Flow Line of Ely Reservoir
Boylston Outlet
WACH
AD

GEOLOGICAL MAP

OF THE

WACHUSETT RESERV

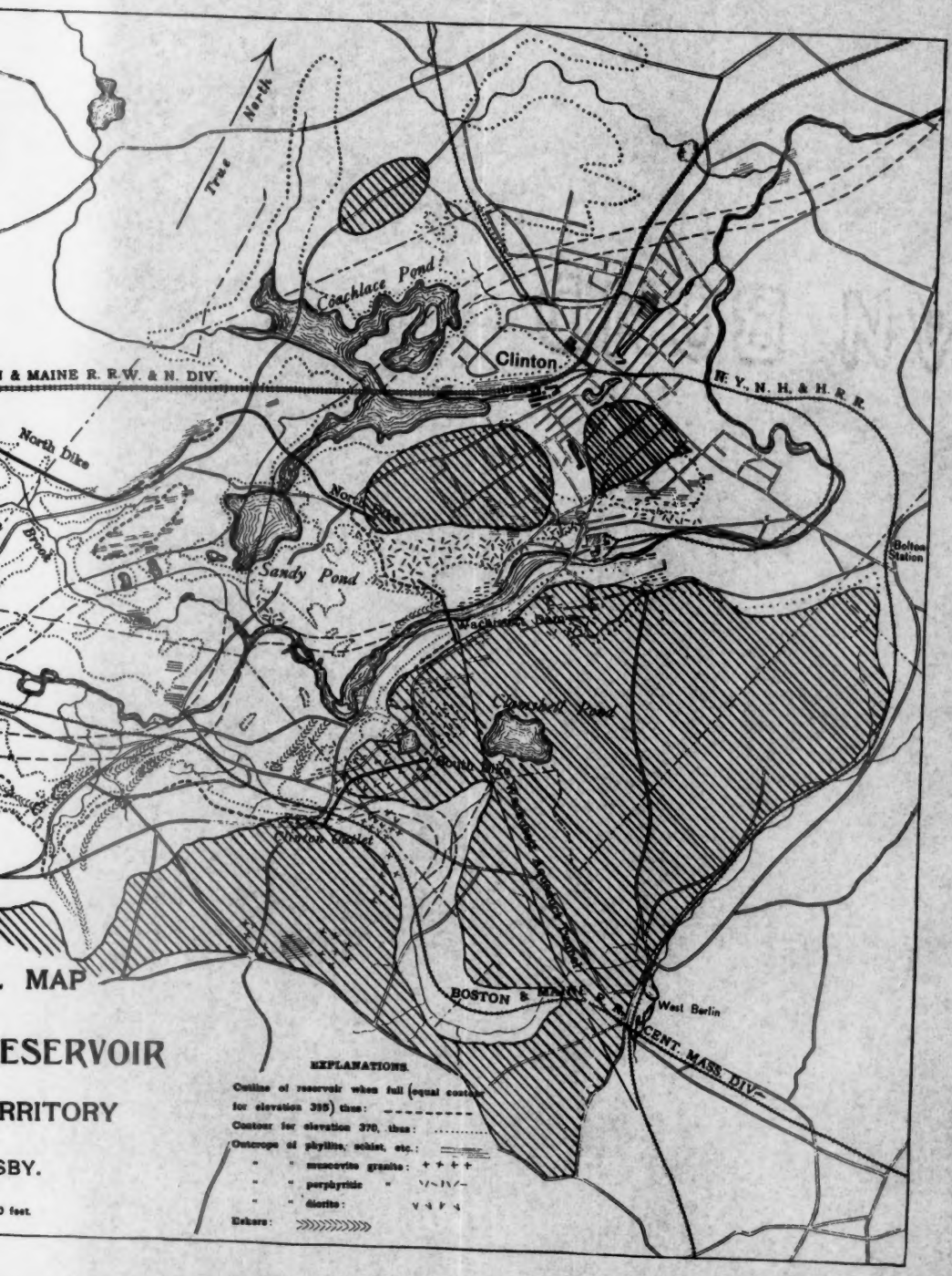
AND

ADJACENT TERRITOR

BY

W. O. CROSBY.

SCALE: 1 inch = 3200 feet.



. MAP

ESERVOIR

RRITORY

SBY.

0 feet.

Washita River

which was probably raised somewhat by the extension through it of the coarse top-set layers of the delta.

The marked narrowing of the valley at Boylston, so well indicated on the map by the flow line of the reservoir, is due chiefly to a broad and well-preserved remnant of the Boylston plain, with the full normal elevation of 440 feet, which juts into the valley from the southward, terminating on the northwest in a well-marked erosion slope rising abruptly nearly 150 feet above the river, and on the northeast in an irregular but typical ice-contact slope, with tributary eskers, overlooking the Clinton plains. The narrowing of the valley at this point is due in part, also, to the protrusion into it from the northward of the high level marginal plain of the early Clinton stage, as described in the preceding paper.[1]

Above this constriction we find, below the Boylston level, first, the narrow and discontinuous marginal plains or terraces of the Clinton level, due to the erosion of the Boylston plains by the Nashua River during the Clinton stage, when the base level was controlled by the South Dike outlet; and second, the flood plains of the modern Nashua, due to the further erosion of the Boylston deposits during the time that the base level in this part of the valley has been determined by the ledge of slate over which the river now flows at Boylston.

Below the constriction, on the other hand, are the broad deltas of the Clinton stage, divided at a level some 80 feet lower by the flood plains of the modern river, due to the erosion of the Clinton deposits during the time that the base level in this part of the valley has been determined by the ledge of granite forming the bed of the river at the Lancaster mills in Clinton.

Immediately below Boylston the valley widens rapidly where it intersects the valleys of the ancient Wachusett River and its tributaries,[2] and this intersection of the ancient and modern drainage affords a ready explanation at once of the exceptional width and of the complexity of this part of the valley, in which the Clinton plains are developed almost exclusively.

As the map so clearly shows, the Clinton plains terminate on the east and west against slopes of rock and till, and on the south against the ice-contact slope and eskers of the Boylston plain. Although it

[1] Technology Quarterly, 12, 318.

[2] Technology Quarterly, 12, 309.

appears impossible to escape the conclusion that the earlier, or southern part, at least, of the Clinton plain was formed largely of material derived by the rapid fluvial erosion of the Boylston plain, we find along the main part of this margin, and especially at the base of the best developed portion of the Boylston plain, a well-marked foss, or depression, which is, however, more or less discontinuous, consisting of a series of kettles and basins clearly indicative of buried masses of ice rather than of a failure of the Clinton delta to fill its basin in this direction, and testifying to the promptness with which deposition,

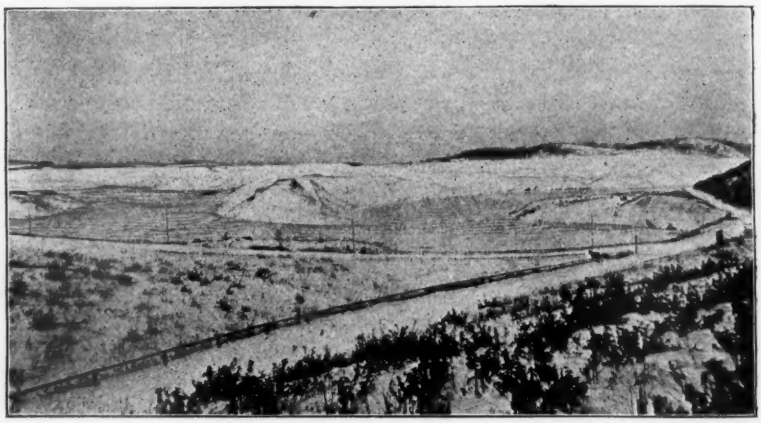


FIG. 1. — VIEW OF THE EASTERN END OF THE NORTH DIKE PLAIN, LOOKING NORTHWEST ACROSS THE NASHUA RIVER AT THE GREAT BEND, WITH BURDETTE HILL IN THE RIGHT DISTANCE.

chiefly of material washed by the river from the Boylston plain, followed the retreating ice margin.

To the eastward, between the former site of South Clinton station and the South Dike outlet, east and south of the Nashua River, this plain is very fragmentary, much complicated by the eskers of the Boylston stage,[1] and attains its normal elevation for only a small fraction of the area. But west of the river this earliest section of the Clinton plain has its principal and most interesting development. Southward it terminates in the remarkably abrupt and perfect erosion scarp, more than a mile in length and 70 to 80 feet high, overlooking

[1] TECHNOLOGY QUARTERLY, 12, 315.

the river, and northward it presents a very normal ice-contact slope bordering Cunningham Brook for practically its entire length, while to the eastward it ends in a quite well-characterized free frontal slope, and westward it abuts against the higher and older marginal plain. It is thus highly differentiated in its margins, and that it is merely a remnant, the head of a plain once continuous across the modern valley of the river, is obvious. This delta remnant, more than a mile in length, varies in breadth from about 1,000 feet in the eastern half to fully 3,000 feet in the western half, but especially in this broad western portion it is much diversified and subdivided by kettles, the two largest,

FIG. 2.—VIEW ON THE NORTH DIKE PLAIN, LOOKING EAST ACROSS SANDY POND TOWARD THE SOUTH DIKE OUTLET.

one east and one west of the old road from Clinton to Boylston, being indicated on the map. This southernmost original section or member of the Clinton plains, now so widely and deeply divided by the Nashua River, may conveniently be designated the *Nashua plain.*

The valley of Cunningham Brook is throughout virtually a foss between the normally steep and irregular ice-contact margin, just described, on the south, and a normally gentle and lobate frontal slope on the north. Ascending this frontal slope we find ourselves on the extensive section of the Clinton plain traversed from end to end by the North Dike and crossed transversely by the group of rock ridges, on one of which was formerly the Catholic cemetery. This North

Dike plain is the largest and, geologically, the most important of the Clinton plains, made doubly important to the student of glacial geology by the great extent to which it has been dissected by boring and excavation. Its length is measured by the North Dike, and, like that, it abuts at either end against a prominent drumloid. It is not only crossed midway of its length by narrow ridges of contorted schist, but it is nearly divided in the eastern half by a prominent line of kettles, the largest of which holds Sandy Pond. Still farther east, between Sandy Pond and the Nashua River and in the lee of Burdette Hill, the plain becomes very fragmentary, and is finally reduced

FIG. 3.—VIEW ON THE NORTH DIKE PLAIN, LOOKING WEST TOWARD THE PROMINENT DRUMLOID AGAINST WHICH THE NORTH DIKE TERMINATES.

to a maze of interlacing kames inclosing numerous kettles and irregular hollows. Figure 1 is a somewhat distant view of this area looking northeasterly across the great bend of the Nashua, where the river finally turns to the northward parallel with the main axis of the valley. The North Dike plain, steadily gaining in height northward, terminates in that direction in a very typical ice-contact slope, diversified by kettles and following closely the southern border of Coachlace Pond. The limits here defined give the North Dike plain an extreme length, east-west, of a little over two miles, and a maximum breadth between the ice-contact and frontal slopes of about a mile. Figures 2, 3, and 4 are general views across the North Dike plain before the construction of the dike.

Coachlace Pond, like Cunningham Brook, occupies a foss between successive segments of the Clinton delta. The plains north of the pond, although almost ideal in development, are much less extensive than the North Dike and Nashua plains, and, unlike the southern plains, do not span the entire breadth of the valley.

First in order comes the Mossy Pond plain in the southeastern angle of the Boston and Maine and the New York, New Haven and Hartford Railroads. It is divided nearly transversely by the northern lobe of Coachlace Pond, known as Mossy Pond — as the North Dike plain is divided by Sandy Pond and contiguous kettles. Notwithstanding its divided form, and this is clearly an original feature due to kettle hole development, this is a beautifully perfect and normal plain, terminating southward in a gentle frontal slope, and northward, for part of its length, in a broken ice contact, and partially surrounding a small drumlin on its northwestern border. This plain is almost or virtually continuous across the New Haven Railroad, with the singularly perfect square plain nearly three-fourths of a mile in diameter in the northeastern angle of the two railroads, mainly in Clinton and partly in Lancaster, and admirably expressed on the topographic map. This plain — *Lancaster plain*, as we may call it — presents ice-contact slopes to the north and east, but the frontal slope, as noted, merges to the

FIG. 4. — BURDETTE HILL, LOOKING NORTHEAST FROM THE NORTH DIKE, AND SHOWING THE STRAIGHT AND SHARPLY DEFINED CONTACT OF THE PLAIN AND THE HILL.

west with the ice contact of the Mossy Pond plain, and the foss is only partially developed.

No trace of the Clinton delta has been observed north of this fourth segment, and it is interesting to find its last expression so ideal in development. We cannot escape the conclusion that north of the Lancaster plain the retreat of the ice margin was too continuous and rapid to permit the development of mature delta plains in the increasingly greater depths of Lake Nashua; but it is equally certain that up to this latitude the recession was intermittent, with three and probably four halts of sufficient length to allow the glacial streams to extend their united deltas across the basin, the maximum development being thus approximately realized for all but the Mossy Pond delta. It thus appears that with each halt of the ice margin the lake basin, due to recession of the ice, was nearly or quite obliterated by the encroachment of its own deposits.

The lines of halting cannot be correlated with the prelacustrine topography, and were clearly not determined by the configuration of the valley; but it is significant that throughout — and more and more with increasing latitude — the ice continued to occupy the eastern side of the valley after the western side was free, with, however, conditions favorable to the development of a nearly continuous line of kettles and basins across the successive deltas along the most probable course of the buried gorge of the Nashua River.[1]

The extreme range in latitude of the Clinton plains is nearly four miles, but the shore of this stage of Lake Nashua can be identified at some points where no important deposit was made. Thus, Walnut Street in the village of Clinton, on which is the office of the Metropolitan Water Works, occupies a natural terrace on the western slope of the Cedar Hill drumloid which agrees in elevation with the Clinton plains and is clearly a beach of Lake Nashua formed after the ice margin had receded from the latitude of Clinton, or during the latter part of the Clinton stage. No attempt has been made to trace this shore farther north, but it should be possible, apparently, to identify it at least as far north as Harvard. It is obvious, however, that this record of the glacial lake must become less distinct northward, as the time available for its inscription was more brief.

Tributary Eskers. — The double line of eskers in the vicinity of

[1] Technology Quarterly, **12**, 293–300.

South Clinton station has been referred to the Boylston stage,[1] and the knob of coarse gravel rising from the Nashua plain midway of the length of its northern erosion scarp is best regarded as a buried remnant of still another esker of the Boylston stage. The only well-characterized esker to be safely correlated with the Clinton stage or regarded as tributary to the Clinton plains is the very normal example closely bordering the west bank of the Nashua River for one-fourth of a mile immediately south of the Wachusett Dam, and probably continued in the double line of esker south of the great bend of the

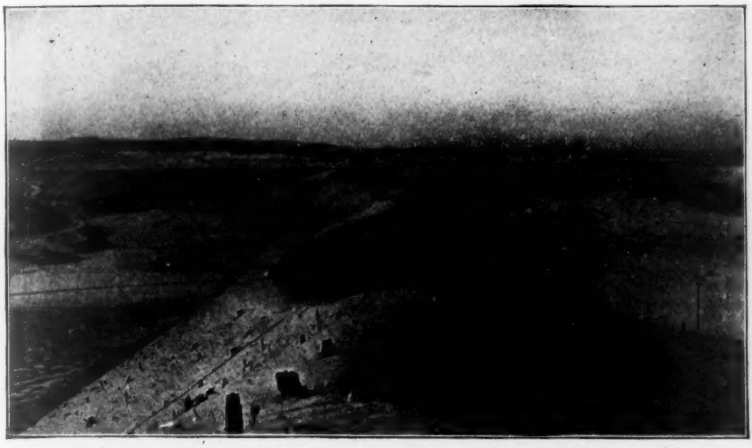


FIG. 5. — VIEW LOOKING SOUTH FROM THE WESTERN END OF THE WACHUSETT DAM, SHOWING THE ESKER BORDERING THE NASHUA RIVER, AND ON THE RIGHT THE TUMULTUOUS EASTERN END OF THE NORTH DIKE PLAIN.

river. At the northern end this esker agrees closely in height with, and is covered by or lost in, a fragment or outlier of the North Dike plain lying against the southeastern base of Burdette Hill. The view southward from this point (Figure 5) shows the esker in its relations to the river and to the tumultuous portion of the North Dike plain previously described. This view is almost the reverse of that in Figure 1.

In this connection, also, may be mentioned the wavering line of eskers on the east side of the Nashua Valley, between Ban Hill Pond and Lancaster Commons. These have been correlated with the Bolton

[1] TECHNOLOGY QUARTERLY, 12, 315.

station outlet of the Clinton stage and the adjacent marginal and apron plains.[1]

Marginal Slopes. — As previously explained, the marginal slopes of the Clinton plains include normal examples of original ice-contact and frontal slopes and secondary erosion slopes. Both types of original slopes are more or less perfectly developed on each one of the four successive members of the Clinton series, and are combined to form a typical foss between the North Dike and Nashua plains. (Figure 6.) To the westward this foss, which is the valley but not the product of

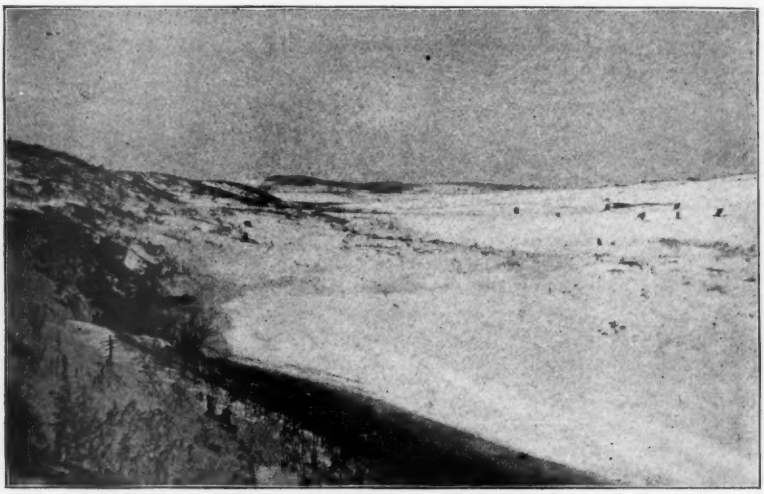


FIG. 6. — VIEW LOOKING UP THE FOSS VALLEY OF CUNNINGHAM BROOK, WITH THE ICE-CONTACT SLOPE OF THE NASHUA PLAIN ON THE LEFT, AND THE FRONTAL SLOPE OF THE NORTH DIKE PLAIN ON THE RIGHT.

Cunningham Brook, expands, through the failure of the North Dike plain to attain in this direction the possible maximum area, into a broad meadow comparable in its geological relations to the basin of Coachlace Pond. Eastward, also, Cunningham Brook, before joining the Nashua, flows through a broad and deep basin floored in part by granite ledges and bowlder clay, but clearly due in this instance, as indicated by the steep slopes to the north and west, to the burial and subsequent melting of a block of ice.

[1] TECHNOLOGY QUARTERLY, **12**, 321.

Erosion slopes find their only striking development in the plains of the Clinton series, in the valley from 2,000 to 3,000 feet wide which the Nashua River has cut through the Nashua plain east of Boylston. These erosion scarps (Figure 7) are ideal in their steepness, height, absolute definition above and below, and in their splendid concave curves and salient cusps, with abandoned channels of the river at the base or meandering across the flood plain.

What it was that first determined the course of the Nashua across

FIG. 7. — EROSION SLOPE OF THE NASHUA PLAIN ON THE SOUTH SIDE OF THE NASHUA RIVER EAST OF BOYLSTON.

the plain below Boylston to the eastward instead of the northeastward along the line of great kettles we can only conjecture, but a foss similar to that occupied by Cunningham Brook is, perhaps, the most probable suggestion; and we may readily believe that a controlling factor was the fact that all the Clinton plains either become very fragmentary or die out altogether toward the east side of the valley. In other words, on the final withdrawal of the waters of Lake Nashua by the opening of the outlet at Ayer, the river simply took the most direct course to an open channel at a low level, and the linear series

of kettles, described in the next section, evidently lacked the continuity necessary to determine the choice of that line.

Kettles. — Kettles, or depressions due to the melting of buried or partially buried masses of ice, are a feature of nearly all the ice-contact margins, and their entirely normal relations make them of rather less interest than the series of large, longitudinal kettles and basins previously referred to as more or less completely dividing in a north-south direction all but the Lancaster plain. This series is most strikingly developed in Mossy Pond, the southern lobe of Coachlace Pond, and Sandy Pond (Figure 8), and from Sandy Pond a practically continuous

FIG. 8. — SANDY POND FROM THE NORTHEAST, AS IT APPEARED BEFORE THE DEFORESTING OF THE NORTH DIKE PLAIN.

line of large kettles (Figure 9) extends southwesterly to Cunningham Brook. Three of these kettles are deep enough to hold permanent kettle ponds. Across the northern section of the Nashua plain to its bold erosion scarp the principal development of kettles bears still more to the southwest and is, perhaps, less continuous, although it includes one large and deep example, which is greatly elongated in the direction of the series, and also finds expression in the 370-foot contour on the map.

The continuity and directness of this line to Cunningham Brook is clearly shown on the map, which also brings out clearly the fact, previously noted, that these depressions coincide approximately or exactly

with the most probable course of the buried gorge of the Nashua River. This relation has been very fully demonstrated for the territory south of the Boston and Maine Railroad by numerous deep borings, and its recognition raises one of the most interesting questions presented by the study of kettles; that is, the mode and conditions of their formation. The usual conception of a kettle presupposes a residuary block of ice, isolated by melting (or possibly by floating, as in the case of a stranded berg), resting on rock or ground moraine, covered by modified drift, and subsequently melted. But here we have kettles of very typical forms and widely varying sizes which are not floored or under-

FIG. 9. — KETTLE HOLE IN THE NORTH DIKE PLAIN SOUTHWEST OF SANDY POND, WITH THE CEMETERY RIDGE IN THE BACKGROUND.

lain by rock or till, but by sand and gravel 100 feet or more in thickness. This fact, together with the complete absence of till from the section, makes it, apparently, impossible to attribute these kettles to the burial and melting of truly residuary fragments of the ice sheet. The further discussion of this question may best be reserved, however, for a later section on the structures of the deltas.

The basin of Sandy Pond is the largest and deepest of all the kettles. The map and Figure 8 clearly exhibit its features above its normal water level (334 feet). The maximum depth, before the level was lowered during the construction of the North Dike, was 66 feet,

the elevation of the bottom being 268 feet. It is interesting to note that the normal water level of Sandy Pond was nearly 55 feet above that of the Nashua River only a little more than a quarter of a mile to the southeast, and the strip of the North Dike plain separating the basin of the pond from the still larger basin in which the foss valley of Cunningham Brook terminates is so narrow, being hardly wider than a normal esker, as to permit a strong outward flow of the water from Sandy Pond. This leakage gave rise to a brook which, although only a quarter of a mile long, often exceeded Cunningham Brook in the volume of water delivered to the river.

(*To be continued.*)

THE METALLURGY OF LEAD.[1]

By H. O. HOFMAN.

In the last twenty years of the nineteenth century the lead-smelting industry underwent important changes. Most of these were the result of new conditions arising in the United States, where the treatment of the ores is carried out, not in small works near the mines, but in large, centrally-situated smelting plants, to which the ores are shipped from various mining regions. As the competition is considerable all the details of work have been greatly improved, the cost reduced, and the yield increased. Lead ores are smelted in the reverberatory furnace, the ore hearth, and the blast furnace. The use of the first two is restricted, as they are suited only for galena ores (the more common), or mixtures of galena and carbonate, which contain not less than 58 per cent. of lead and not more than 4 per cent. of silica; further, ores to be treated in the ore hearth should run low in or be free from silver, as the loss in the fumes is excessive. In the blast furnace all lead ores are successfully smelted. Blast-furnace treatment has, therefore, become more general than any other.

To the two methods of working in the reverberatory furnace, represented by the English and Carinthian furnaces (described in *Encyclopædia Britannica*, Vol. XIV, p. 375), a third, the Silesian, must be added. While by the former processes as much lead as possible is extracted in the furnace, with the Silesian method a very low temperature is used, thus taking out about one-half of the lead and leaving very rich slags (50 per cent. lead) to be smelted in the blast furnace, the ultimate result being a very much higher yield than by either of the other processes. The Silesian furnace has an oblong hearth, 16 feet by 8 feet 10 inches, sloping from the fire bridge to the flue bridge. This causes the lead to collect at the coolest part of the hearth,

[1] Reprinted, by permission of the publishers, from the article on Lead, by Prof. H. O. Hofman, in the new volumes of the *Encyclopædia Britannica*, copyright 1902, by the Encyclopædia Britannica Company.

whence it is tapped, etc., as in the English furnace. A charge of 6,180 pounds of galena ore (70 per cent. lead) is worked in twelve hours by three men, 0.46 ton of coal being consumed per ton of ore charged. The loss in lead by the combined reverberatory and blast-furnace treatment is only 3.2 per cent.

In the hearth process the blocks of cast iron forming the sides and back of the Scottish furnace (see *Encyclopædia Britannica*, Vol. XIV, p. 375) are now generally replaced in the United States by water-cooled shells (water jackets) of cast iron. In this way continuous working has been rendered possible, whereas formerly operations had to be stopped every twelve or fifteen hours to allow the over-heated blocks and furnace to cool down. The latest improvement (which somewhat changes the mode of working) is that by Moffett. While he also prevents interruption of the operation by means of water jackets, he uses hot blast, and produces, besides metallic lead, large volumes of lead fumes, which are drawn off by fans through long cooling tubes, and then forced through suspended bags which filter off the dust, called blue powder. This, a mixture of lead sulphate (45 per cent.) and oxide (44 per cent.), with some sulphide (8 per cent.), zinc, and carbonaceous matter, is agglomerated by a heap-roast, and then smelted in a slag-eye furnace with gray slag from the ore hearth. The furnace has, however, in addition to the usual tuyères near the bottom, a second set near the throat, in order to effect a complete oxidation of all combustible matter. Much fume is thus produced. This is drawn off, cooled, and filtered, and forms a white paint of good body, consisting of about 65 per cent. lead sulphate, 26 per cent. lead oxide, 6 per cent. zinc oxide, and 3 per cent. other substance. Thus, in the Moffett method, it is no matter whether metal or fume is produced, as in either case it is saved and the price is about the same.

In smelting at once in the same blast furnace ores of different character, the old use of separate processes of precipitation, roasting and reduction, and general reduction prevailing in the Harz Mountains (see *Encyclopædia Britannica*, Vol. XIV, p. 376), Freiberg, and other places, to suit local conditions, has had to be abandoned. Ores are smelted raw if the fall of matte (metallic sulphide) does not exceed 5 per cent.; otherwise they are subjected to a preliminary oxidizing roast to expel the sulphur, unless they run too high in silver, say 100 ounces to the ton, when they are smelted raw. The leading reverber-

atory furnace for roasting lead-bearing sulphide ores has a level hearth 14–16 feet wide and 60–80 feet long. It puts through 9–12 tons of ore in twenty-four hours, reducing the percentage of sulphur to 2–4 per cent., and requires four to six men and about two tons of coal. In many instances it has been replaced by mechanical furnaces, which are now very common in roasting sulphide copper ores. (See Acid and Alkali Manufacture.) A modern blast furnace is oblong in horizontal section, and about 24 feet high from furnace floor to feed floor. The shaft, resting upon arches supported by four cast-iron columns about 9 feet high, is usually of brick — red brick on the outside, fire brick on the inside; sometimes it is made of wrought-iron water jackets. The smelting zone always has a bosh and a contracted tuyère section. It is enclosed by water jackets, which are usually cast iron, sometimes mild steel. The hearth always has an Arents siphon tap. This is an inclined channel running through the side-wall, beginning near the bottom of the crucible and ending at the top of the hearth, where it is enlarged into a basin. The crucible and the channel form the two limbs of an inverted siphon. While the furnace is running, the crucible and channel remain filled with lead; all the lead reduced to the metallic state in smelting collects in the crucible, and rising in the channel overflows into the basin, whence it is removed. The slag and matte formed float upon the lead in the crucible and are tapped, usually together, at intervals into slag-pots, where the heavy matte settles on the bottom and the light slag on the top. When cold they are readily separated by a blow from a hammer. The following table gives the dimensions of some well-known American lead furnaces:

Locality.	Lead Blast-Furnace.		Height Tuyère to Throat.
	Year.	Tuyère Section.	
		Inches.	Feet.
Leadville, Colorado	1880	33 x 84	14
Denver, "	1880	36 x 100	17
Durango, "	1882	36 x 96	12.6
Denver, "	1892	42 x 100	16
Leadville, "	1892	42 x 120	18
Salt Lake City, Utah	1895	45 x 140	20

A furnace 42 by 120 inches at the tuyères, with a working height of 17–20 feet, with twelve men, using 12 per cent. of coke and two-pound blast pressure, will put through in twenty-four hours 85–100 tons average charge, *i.e.*, one that is medium coarse, which contains 12–15 per cent. lead, not over 5 per cent. zinc, and makes under 5 per cent. matte. In making up a charge the ores and fluxes whose chemical compositions have been determined are mixed so as to form typical slags out of the components not to be reduced to the metallic or sulphide state (silicates of ferrous and calcic oxides, incidentally of aluminium oxide, which have been found to do successful work). Such slags contain SiO_2 30–33 per cent., Fe(Mn)O 27–50 per cent., Ca(Mg, Ba)O 12–28 per cent., and retain less than 1 per cent. lead and 1 ounce silver to the ton. The leading products of the blast furnace are argentiferous lead (base bullion), matte, slag, and flue dust (fine particles of charge and volatilized metal carried out of the furnace by the ascending gas current). The base bullion (assaying 300 ± ounces per ton) is desilverized (see below); the matte (Pb 8–12 per cent., Cu 3–4 per cent., Ag $\frac{1}{3}$–$\frac{1}{5}$ of the assay value of the base bullion, rest Fe and S) is roasted and resmelted, when part of the argentiferous lead is recovered as base bullion, while the rest remains with the copper, which becomes concentrated in a copper matte (60 per cent. copper), to be worked up by separate processes (see Copper). The slag is a waste product, and the flue dust, collected by special devises in dust chambers, is briquetted by machinery, with lime as a bond, and then resmelted with the ore charge. The yield in lead is over 90 per cent., in silver over 97 per cent., and in gold 100 per cent. The cost of smelting a ton of ore in Colorado in a single furnace 42 by 120 inches at the tuyères is about three dollars.

Refining. — The lead produced in the reverberatory furnace and the ore hearth is of a higher grade than that produced in the blast furnace, as the ores treated are purer and richer, and the reducing action is less powerful. The following analysis of blast furnace lead of Freiberg, Saxony, is from an exceptionally impure lead: Pb 95.088, Ag 0.470, Bi 0.019, Cu 0.225, As 1.826, Sb 0.958, Sn 1.354, Fe 0.007, Zn 0.002, S 0.051. Of the impurities most of the copper, nickel and copper, considerable arsenic, some antimony, and small amounts of silver, are removed by liquation. The lead is melted down slowly, when the impurities separate in the form of a scum (dross) which is easily

removed. The purification by liquation is assisted by poling the lead when it is below redness. A stick of green wood is forced into it, and the vapors and gases set free stir it up and expose new surfaces to the air, which at this temperature has only a mildly oxidizing effect. The pole, the use of which is awkward, has been replaced by dry steam, which has a similar effect. In order to remove tin, arsenic, and antimony, the lead has to be brought up to a bright red heat, when the air has a strongly oxidizing effect. Tin is removed mainly as a powdery mixture of stannate of lead and lead oxide; arsenic and antimony, as a slagged mixture of lead oxide and arsenate and antimonate of lead. They are readily withdrawn from the surface of the lead and are worked up into antimony (arsenic), tin-lead, and antimony-lead alloys. Liquation, if not followed by poling, is carried on as a rule in a reverberatory furnace with an oblong, slightly trough-shaped inclined hearth; if the lead is to be poled it is usually melted down in a cast-iron kettle. If the lead is to be liquated and then brought to a bright red heat, both operations, for convenience' sake, are carried on in the same reverberatory furnace. This has an oblong, dish-shaped hearth of acid or basic fire brick built into a wrought-iron pan, which rests on transverse rails supported by longitudinal walls. The lead is melted down at a low temperature and drossed. The temperature is then raised, and the scum which forms on the surface is withdrawn until pure litharge forms, which only takes place after all the tin, arsenic, and antimony have been eliminated.

Desilverizing. — Silver is extracted from lead by means of the process of cupellation (see *Encyclopædia Britannica*, Vol. XIV, p. 376). Formerly all argentiferous lead had to be cupelled, and the resulting litharge then reduced to metallic lead. In 1833 Pattinson invented his process (*ibid.*, p. 377) by means of which practically all the silver is concentrated in 13 per cent. of the original lead to be cupelled, while the rest becomes market lead. In 1842 Karsten (*loc. cit.*) discovered that lead could be desilverized by means of zinc. His invention, however, only took practical form in 1850–2, through the researches of Parkes, who showed how the zinc-silver-lead alloy formed could be worked and the desilverized lead freed from the zinc it had taken up. In the Parkes process only 5 per cent. of the original lead need be cupelled. Thus, while cupellation still furnishes the only means for the final separation of lead and silver, it has become an auxiliary process to the two methods of concentration given. Of these the Pattin-

son process has become subordinate to the Parkes process, as it is more expensive and leaves more silver and impurities in the market lead. It holds its own, however, when base bullion contains bismuth in appreciable amounts, as in the Pattinson process bismuth follows the lead to be cupelled, while in the Parkes process it remains with the desilverized lead which goes to market, and lead of commerce should contain little bismuth. At Freiberg, Saxony, the two processes have been combined. The base bullion is imperfectly Pattinsonized, giving lead rich in silver and bismuth, which is cupelled, and lead low in silver, and especially so in bismuth, which is further desilverized by the Parkes process.

The effect of the two processes on the purity of the market lead is clearly shown by the two following analyses by Hampe, which represent lead from Lautenthal, in the Harz Mountains, where the Parkes process replaced that of Pattinson, the ores and smelting process remaining practically the same:

Process.	Pb.	Cu.	Sb.	As.	Bi.	Ag.	Fe.	Zn.	Ni.
Pattinson	99.966200	0.015000	0.010000	none	0.000600	0.002200	0.004000	0.001000	0.001000
Parkes	99.983139	0.001413	0.005698	none	0.005487	0.000460	0.002289	0.000834	0.000680

Cupelling. — The reverberatory furnace commonly used for cupelling goes by the name of the English cupelling furnace. It is oblong, and has a fixed roof and a movable iron hearth (test). Formerly the test was lined with bone ash; at present the hearth material is a mixture of crushed limestone and clay (3:1), or Portland cement, either alone or mixed with crushed fire brick; in a few instances the lining has been made of burnt magnesite. In the beginning of the operation enough argentiferous lead is charged to fill the cavity of the test. After it has been melted down and brought to a red heat, the blast, admitted at the back, oxidizes the lead and drives the litharge formed towards the front, where it is run off. At the same time small bars of argentiferous lead, inserted at the back, are slowly pushed forward, so that in melting down they may replace the oxidized lead. Thus the level of the lead is kept approximately constant, and the silver becomes concentrated in the lead. In large works the silver-lead alloy is removed when it contains 60–80 per cent. silver, and the cupella-

tion of the rich bullion from several concentration furnaces is finished in a second furnace. At the same time the silver is brought to the required degree of fineness, usually by the use of nitre. In small works the cupellation is finished in one furnace, and the resulting low-grade silver fined in a plumbago crucible, either by overheating in the presence of air, or by the addition of silver sulphate to the melted silver, when air or sulphur trioxide and oxygen oxidize the impurities. The lead charged contains about 1.5 per cent. of silver if it comes from a Pattinson plant, from 5–10 per cent. if from a Parkes plant. In a test 7 feet by 4 feet 10 inches, and 4 inches deep, about 6 tons of lead are cupelled in twenty-four hours. A furnace is served by three men, working in eight-hour shifts, and requires about two tons of coal, which corresponds to about 110 gallons reduced oil, air being used as atomizer. The loss in lead is about 5 per cent. The latest cupelling furnaces have the general form of a reverberatory copper-smelting furnace. The working door through which the litharge is run off lies under the flue which carries off the products of combustion and the lead fumes; the lead is charged and the blast is admitted near the fire bridge.

Pattinson Process. — In the Pattinson process the argentiferous lead is melted down in the central cast-iron kettle of a series of 8–15, placed one next to the other, each having a capacity of 9–15 tons and a separate fireplace. The crystals of impoverished lead which fall to the bottom upon coaling the charge are taken out with a skimmer and discharged into the neighboring kettle (say to the right) until about two-thirds of the original charge has been removed, then the liquid, enriched lead is ladled into the kettle on the opposite side. To the kettle, two-thirds full of crystals of lead, is now added lead of the same tenor in silver, the whole is liquidified, and the cooling, crystallizing, skimming, and ladling are repeated. The same is done with the kettle one-third filled with liquid lead, and so on until the first kettle contains market lead, the last cupelling lead. The intervening kettles contain leads with silver contents ranging from above market to below cupelling lead. The original Pattinson process has been in many cases replaced by the Luce-Rozan process (1870), which does away with arduous labor and attains a more satisfactory crystallization. The plant consists of two tilting oval metal pans (capacity 7 tons), one cylindrical crystalling pot (capacity 22 tons), with two discharging spouts, and one steam-inlet opening, two lead molds (capacity

3½ tons), and a steam crane. Pans and pot are heated from separate fireplaces. Supposing the pot to be filled with melted lead to be treated, the fire is withdrawn beneath and steam introduced. This cools and stirs the lead, when crystals begin to form. As soon as two-thirds of the lead has separated out in the form of crystals the steam is shut off and the liquid lead drained off through the two spouts into the molds. The fire underneath the pot is again started, the crystals are liquidified, and one of the two pans, filled with melted lead, is tilted by means of the crane and its contents poured into the pot. In the meantime the lead in the molds, which has solidified, is removed with the crane and stacked to one side until its turn comes to be raised and charged into one of the pans. The crystallization proper lasts one hour, the working of a charge four hours, six charges being run in twenty-four hours.

Parkes Process.—It is absolutely necessary for the success of the Parkes process that the zinc and lead should contain only a small amount of impurity. The spelter used must, therefore, be of a good grade, and the lead is usually first refined in a reverberatory furnace (the softening furnace) as described above. The capacity of the furnace must be 10 per cent. greater than that of the kettle into which the softened lead is tapped, as the dross and skimmings formed amount to about 10 per cent. of the weight of the lead charged. The kettle is spherical, and is suspended over a fireplace by a broad rim resting on a wall; it is usually of cast iron. Most kettles at present hold 30 tons of lead; some, however, have double that capacity, When zinc is placed on the lead (heated to above the melting point of zinc), liquidified, and brought into intimate contact with the lead by stirring, then gold, copper, silver, and lead will combine with the zinc in the order given. By beginning with only a small amount of zinc all the gold and copper, and some silver and lead, will be alloyed with the zinc to a so-called gold or copper crust, and the residual lead will be saturated with zinc. By removing from the surface of the lead this first crust and working it up separately (liquating, retorting, and cupelling), doré silver is obtained. By the second addition of zinc most of the silver will be collected in a saturated zinc-silver-lead crust, which, when worked up, gives fine silver. A third addition becomes necessary to remove the rest of the silver when the lead will assay only 0.1 ounce silver per ton. As this complete desilverization is only possible by the use of an excess of zinc, the unsaturated zinc-silver-lead alloy is

put aside to form part of the second zincing of the next following charge. In skimming the crust from the surface of the lead some unalloyed lead is also drawn off and has to be separated by an additional operation (liquation); as, running lower in silver than the crust, it would otherwise reduce its silver content and increase the amount of lead to be cupelled. A zincing takes 5–6 hours; 1.5–2.5 per cent. of zinc is required for desilverizing. The liquated zinc-silver-lead crust contains 5–10 per cent. of silver, 30–40 per cent. zinc, and 65–50 per cent. lead. Before it can be cupelled it has to be freed from most of the zinc, which is accomplished by distilling in a retort made of a mixture similar to that of the plumbago crucible. The retort is pear-shaped, and holds 1,000–1,500 pounds of charge, consisting of liquated crust mixed with 1–3 per cent. of charcoal. The condenser commonly used is an old retort. The distillation of 1,000 pounds charge lasts 5–6 hours, requires 500–600 pounds of coke, or 30 ± gallons of reduced oil, and yields about 10 per cent. metallic zinc, and 1 per cent. blue powder, a mixture of finely divided metallic zinc and zinc oxide. About 60 per cent. of the zinc used in desilverizing is recovered in a form to be used again. One man serves 2–4 retorts. The desilverized lead, which retains 0.6–0.7 per cent. of zinc, has to be refined before it is suited for industrial use. The operation is carried on in a reverberatory furnace or in a kettle. In the reverberatory furnace, similar to the one used in softening, the lead is brought to a bright red heat and air allowed to have free access. The zinc and some lead are oxidized; part of the zinc passes off with the fumes, part is dissolved by the litharge, forming a melted mixture which is skimmed off and reduced in a blast furnace or a reverberatory smelting furnace. In the kettle covered with a hood the zinc is oxidized by means of dry steam, and incidentally some lead by the air which cannot be completely excluded. A yellowish powdery mixture of zinc and lead oxides collects on the lead; it is skimmed off and sold as paint. From the reverberatory furnace or the kettle the refined lead is siphoned off into a storage (market) kettle after it has cooled somewhat, and from this it is siphoned off into molds placed in a semicircle on the floor. In the process the yield in metal, based upon the charge in the kettle, is lead, 99 per cent.; silver, 100+ per cent.; gold, 98–100 per cent. The plus silver is due to the fact that in assaying the base bullion by cupellation the silver lost by volatilization and cupel absorption is neglected. In the

United States the cost of desilverizing a ton of base bullion is about six dollars.

Statistics. The world's production of lead in 1899 was, according to *The Mineral Industry* (1900, p. 431), 803,273 metric tons, viz.: Austria, 9,736; Belgium, 15,700; Canada, 9,917; Chile, 171; France, 15,981; Germany, 129,225; Greece, 19,059; Hungary, 2,166; Italy, 20,543; Japan, 1,989; Mexico, 84,656; New South Wales, 70,000; Russia, 250; Spain, 184,007; Sweden, 1,606; United Kingdom, 41,500; United States, 196,938.

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THE METALLURGY OF SILVER.[1]

By H. O. HOFMAN.

From the metallurgical point of view silver ores may be classified as real silver ores and argentiferous ores. The former consist of silver minerals and gangue (vein matter, country rock). The leading silver minerals are native silver, Ag; cerargyrite, AgCl; argentite, Ag_2S; proustite, $3Ag_2S + As_2S_3$; pyrargyrite, $3Ag_2S + Sb_2S_3$; polybasite, $9Ag_2S + As_2S_3$, and stephanite, $5Ag_2S + Sb_2S_3$. The silver is commonly recovered by milling, *i.e.*, amalgamation or lixiviation. Argentiferous ores consist of silver-bearing base metal minerals and gangue. Lead and copper ores, carrying silver in some form or other, are the leading representatives. The silver is extracted from the gangue with the base metal, usually by smelting, and the two are then separated by special processes (see Lead, Copper). Milling is cheaper than smelting, but the yield in silver is lower. Often it is more profitable to smelt real silver ores with argentiferous ores than to mill them, the greater cost being more than balanced by the increased yield. Milling is practised mainly in isolated localities near the mine producing the ore. As any given region is opened up by railways, cheapening transportation, milling is apt to give way to smelting. Thus, on the American continent, which produces the bulk of the world's silver, milling is still prominent in South America and Mexico, while in the United States it has, to a considerable extent, been replaced by smelting.

Amalgamation is based on the property of quicksilver to extract the silver from finely pulverized ore and collect it in the form of an amalgam. When the rock has been separated from the amalgam by a washing operation, the quicksilver is recovered by distillation in an iron retort, and the remaining crude retort silver melted into bars and shipped to a refinery, which removes the impurities, the leading one of

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which is copper. A silver ore is either free milling or refractory; that is, the silver mineral is readily amalgamated or it is not. In free-milling ore the silver is present either in the native state, or as chloride, or as simple sulphide. Complex silver minerals (sulph-arsenides and antimonides) which are difficult to amalgamate must be made amenable to quicksilver, and the simplest way of doing this is to convert the silver into chloride. This is imperfectly accomplished, in the wet way, by cupric and cuprous chloride solutions, but completely so, in the dry way, by roasting with salt (chlorodizing roasting). According as a preliminary chlorodizing roast has or has not been given, the process is classed as roast amalgamation or raw amalgamation. The leading raw amalgamation processes are the Patio and the Washoe; then follow the Cazo, Fondon, and Kröhnke. Of the roast amalgamation processes the European Barrel or Freiberg, the Reese River, and the Francke-Tina are the most important.

The *Patio* process (for an outline of which see *Encyclopædia Britannica*, Vol. XXII, p. 70) is carried out principally in Mexico. It aims at amalgamating the silver in the open in a circular enclosure, the floor of which is generally built of flagstones. In order to facilitate the decomposition of the silver mineral, salt and magistral are worked into the wet pulp, spread out on the floor. Magistral is cupriferous pyrites roasted to convert the copper into soluble sulphate, which is the active agent. The amalgamation proceeds very slowly, as the sole extraneous heat is that of the sun. According to Laur, at Guanaxuato, Mexico, 92.77 per cent. of the total silver recovered was extracted after 12 days, 97.55 per cent. after 25 days, 99.70 per cent. after 28 days, and 100 per cent. after 33 days. The loss of quicksilver in the process is large, owing to the formation of calomel, which is not saved. The yield in silver is low, unless the ores are exceptionally free milling; the bullion produced is high grade, as refractory silver minerals are hardly attacked. The process is suited to easy ores and a region where the climate is warm and dry, and horse or mule power, labor, and quicksilver are cheaper than fuel and water.

The *Washoe* process is the leading raw amalgamation process of the United States, where it was invented, in 1859, by A. B. Paul. It consists in wet-stamping coarsely crushed ore, settling the sands and slimes produced, and grinding and amalgamating them in steam-heated iron pans with or without the use of chemicals (salt and blue vitriol). The ores may contain a larger proportion of sulphurets and complex

silver minerals than with the Patio process and still give a satisfactory extraction. They are crushed to egg size in a rock breaker, and pulverized to pass a 40-mesh sieve in a California stamp mill, which treats in 24 hours about 3 tons per stamp. A 10-stamp mill is fed by one rock breaker, and discharges the liquid pulp into 10–15 wooden settling tanks 9 x 5 x 8 feet, the settled contents of which are shovelled out and charged into the pans. The pan in general use is the combination pan. It has a flat, cast-iron bottom, 5 feet in diameter, and wooden sides about 30 inches high, the lower parts of which are lined with cast iron. In the center is a hollow cone, through which passes the driving shaft, geared from below. This turns the grinding apparatus (driver with muller), which can be raised and lowered. The speed is 60–90 revolutions per minute. To the bottom and muller are attached grinding plates (shoes and dies), which are replaced when worn, and to the sides three wings, to deflect the moving pulp towards the centre and thus establish the necessary pulp current. The lower side of the bottom has also a steam chest. A 10-stamp mill has 4–6 pans, which receive 2-ton charges. In working, the muller is raised half an inch, the pan charged with water and then with ore, the muller is lowered, salt and blue vitriol are added, and the charge is ground for 3–4 hours. The pulp is heated with live steam to about 90° C., and kept at that temperature by exhaust steam in the bottom chest. After grinding, the muller is raised and quicksilver added, and the silver then amalgamated in 3–4 hours. In amalgamating without the use of chemicals finely divided iron, worn from the shoes and dies in the stamp mill and the pan, decomposes cerargyrite and argentite, and the liberated silver is taken up by the quicksilver; the process is hastened by adding salt. When salt and blue vitriol are added to the charge they form sodium sulphate and cupric chloride ($2NaCl + CuSO_4 = Na_2SO_4 + CuCl_2$), both of which are readily soluble in water. Cupric chloride acts upon argentite ($Ag_2S + CuCl_2 = 2AgCl + CuS$), proustite ($4Ag_3AsS_3 + 12CuCl_2 = 8AgCl, 2Ag_2S, 2CuS, As_2S_3, 5S$), pyrargyrite ($2Ag_3SbS_3 + 4CuCl_2 = 6AgCl + 2CuS + Sb_2S_3 + S$), and is also reduced to cuprous chloride by metallic iron ($2CuCl_2 + Fe = Cu_2Cl_2 + FeCl_2$). This salt, insoluble in water but soluble in brine, also acts upon argentite ($Ag_2S + Cu_2Cl_2 = 2AgCl + CuS + Cu$) and pyrargyrite ($2Ag_3SbS_3 + Cu_2Cl_2 = AgCl + Ag_2S + 2Ag + 2CuS + Sb_2S_3$) and would give, with silver sulphide in the presence of quicksilver, the Patio reaction — metallic silver, cupric sulphide, and mercu-

rous chloride ($2Ag_2S + Cu_2Cl_2 + Hg = 4Ag + 2CuS + Hg_2Cl_2$), but the iron decomposes the quicksilver salt ($Hg_2Cl_2 + Fe = Hg_2 + FeCl_2$) setting free the quicksilver. The amalgamation is rapid. Thus Austin found that at the Charleston mills, Arizona, 92.13 per cent. of the total silver recovered was extracted after 1 hour, 94.10 per cent. after 2 hours, 95.92 per cent. after 3 hours, and 100 per cent. after 4 hours. The loss in quicksilver is small, as there is no chemical loss inherent in the process; the yield is relatively high, but the bullion is liable to be low grade on account of copper being precipitated and amalgamated. When the charge has been worked the contents of the pan are discharged into a settler, in which the amalgam is separated from the sands. It has the same general construction as the pan. It is 8 feet in diameter and 3 feet deep. The bottom, slightly conical, has a groove near the circumference to catch the amalgam, which is withdrawn through a discharge spout into a bowl. In the sides, at different levels, are three discharge holes for water and sand. The muller reaches to within 3 inches of the bottom, and makes 12–15 revolutions per minute. In settling, the pulp is diluted by a small stream of water and the thinned pulp drawn off, first through the top discharge hole and then through the other two, the bottom one being about 8 inches above the amalgam. Settling takes about half the time required to work a charge in the pan, hence one settler serves two pans. The amalgam is dipped out from the bowl into a canvas bag (the strainer), to separate the excess of the quicksilver from the pasty amalgam, which is then retorted and melted. The cost of treating a ton of ore in the western part of the United States is from three to seven dollars. At some works treating ores containing sulphurets, which do not yield their silver to quicksilver, concentration apparatus (see Ore Dressing) is inserted between the stamps and the settling tanks to remove the sulphurets, which are worked by themselves; at other works they are recovered from the sands after these have left the settlers. In order to do away with the handling of the wet pulp and to obtain a higher extraction, M. P. Boss has modified the ordinary plant by making the pulp as it flows from the stamps pass through a grinding pan, then through a series of amalgamating pans, followed by a row of settlers.

A 20-stamp mill is served by 12 men in 24 hours. The Washoe process is independent of the climate, but it requires cheap power and an abundance of water.

In the *Cazo*, *Caldron*, or *Hot* process, the pulverized silver ore is boiled in a copper-bottomed wooden vat, first with brine, until the silver has been reduced by the copper, and then with quicksilver. The *Fondon* is an improvement on the Cazo. Bars of copper drawn over the bottom by mules or water power (like the stone drags in the arrastra) grind off fine particles of copper, which hasten the reduction of the silver and diminish the formation of calomel. In the *Kröhnke* process the silver mineral of the pulverized ore is decomposed in a revolving barrel by a hot solution of cuprous chloride in brine in the presence of zinc or lead and quicksilver.

Chloridizing Roasting. — In a chloridizing roast chlorine produces its effect as nascent chlorine or gaseous hydrochloric acid. The leading reagents are salt (NaCl), sulphur trioxide (SO_3, produced in the roasting), and water vapor (H_2O). The decomposition of salt is expressed by $2NaCl + 2SO_3 = Na_2SO_4 + SO_2 + Cl_2$. In the presence of water vapor the following reaction takes place: $2NaCl + SO_3 + H_2O = Na_2SO_4 + 2HCl$. As some water vapor is always present, hydrochloric acid will invariably be formed with the chlorine. The roasting is carried on in hand and mechanical reverberatory furnaces, occasionally in muffle furnaces. A chloridation of over 90 per cent. of the silver is the rule.

The *European Barrel*, or *Freiberg*, process (see *Encyclopædia Britannica*, Vol. XXII, p. 70), perfected at Freiberg, Saxony, was abandoned there in 1856. In the United States it was used quite extensively in Colorado and Nevada, but has now been given up. The main reasons for this are the length of time required to finish a charge, on account of the absence of any extraneous source of heat, and the great care with which operations have to be carried out in order to obtain satisfactory results. The *Reese River* process consists in dry-stamping crushed dried ore and dried salt (separately or together), charging them into a roasting furnace, and amalgamating the chlorodized ore in an iron pan. The general arrangement and construction of a mill resemble those of the Washoe process. The apparatus for drying ore and salt varies greatly, drying-floors, dry-kilns, and continuous mechanical reverberatory furnaces with stationary and revolving hearths being used. The general construction of the pan is the same as in the Washoe process; the management, however, differs. The steam-chest is not used to such an extent, as the bottom would be prematurely corroded; less water is used, as the pulp would become too

thin on account of the soluble salts (sodium chloride, sulphate, etc.) going into solution; and the roasted ore is not ground, as the hot brine readily dissolves the silver chloride from the porous ore, and thus brings it into intimate contact with iron and quicksilver. Chemical reagents are sometimes added — lime or sulphuric acid, to neutralize an excess of acid or alkali; bluestone, to form cuprous chloride with sodium chloride; and iron and zinc, to make the galvanic action more energetic and to reduce the consumption of iron. The rest of the apparatus (settler, retort, crucible, furnace) is the same as with the Washoe process. The Reese River process costs from half as much again to twice as much as the Washoe process.

The *Francke-Tina* process was developed in Bolivia for the treatment of refractory ores rich in zinc blende (ZnS) and tetrahedrite $4(Cu_2, Fe, Zn, Ag_2, Hg_2)S + (Sb, As, Bi)_2S_3$. The ore is given only a partial chloridizing roast, on account of the great loss in silver that would be caused by the formation of zinc chloride ($ZnCl_2$). The large amount of soluble sulphates of iron and copper formed in the roast is made to act upon salt charged in a copper-bottomed amalgamating pan; the chlorides formed finish in the wet way the imperfect chloridation obtained in the furnace.

Lixiviation. — Ores suited for amalgamation can, as a rule, be successfully leached. In leaching, the silver ore is subjected to the action of solvents, which dissolve the silver; from the solution the silver is precipitated and converted into a marketable product.

The leading solvents are aqueous solutions of hyposulphite salts. Sodium chloride, characteristic of the Augustin process (see *Encyclopædia Britannica*, Vol. XXII, p. 70), has almost wholly fallen into disuse; and potassium cyanide, which has become a very important solvent for finely divided gold, is rarely used in leaching silver ores. The use of sodium hyposulphite as solvent, and sodium sulphide as precipitant, was proposed in 1850 by Hauch and Percy, and put into practice in 1858 by Patera (Patera process); calcium hyposulphite with calcium polysulphide was first used by Kiss in 1860 (Kiss process, now obsolete); sodium hyposulphite with calcium polysulphide was adopted about 1880 by Hofmann (Hofmann process); finally, sodium hyposulphite with cuprous hyposulphite was first applied by Russell in 1884, who included in his process the acidulation of the first wash-water (to neutralize any harmful alkaline reaction), and the separation of lead with sodium carbonate from the silver solution previous to precipitating

with sodium sulphide. In all processes the silver ore is finely crushed, usually by rolls, as, because making few fines, they leave the ore in the best condition for leaching. As a rule the ore is subjected to a preliminary chloridizing roast, though occasionally it may be leached raw. The vats in common use are circular wooden tanks, 16–20 feet in diameter and 8–9 feet deep, if the leached ore is to be removed by sluicing; 5 feet, if by shovelling. They have a false bottom, with cloth or gravel filters. The basis of the following outline is the Patera process. The ore, supposed to have been salt-roasted, is charged loosely into the leaching vat and treated with water (to which sulphuric acid or blue vitriol may have been added) to remove soluble salts, which might later on be precipitated with the silver (base-metal chlorides), or might overcharge the solution (sodium chloride and sulphate), or might interfere with the solvent power (sodium sulphate). The vat is filled with water from above or below, in- and out-flow are then so regulated as to keep the ore covered with water. Any silver dissolved by the first wash-water is recovered by a separate treatment. After the wash-water has been drained off, the ore is ready for the silver solvent. This is a solution containing up to 2 per cent. of sodium hyposulphite ($Na_2S_2O_3 + 5aq.$) of which one part dissolves 0.485 parts of silver chloride, = 0.365 parts metallic silver ($2AgCl + 3Na_2S_2O_3 = Ag_2S_2O_3, 2Na_2S_2O_3 + 2NaCl$). Silver arsenate and antimoniate are also readily soluble, metallic silver slightly so, silver sulphide not at all. (In the Russell process the double salts, $4Na_2S_2O_3.3Cu_2S_2O_3$ and $8Na_2S_2O_3.3Cu_2S_2O_3$, and the metallic silver and silver sulphide are readily soluble; thus it supplements that of Patera). After the silver has been dissolved by percolation, the last of the solvent still in contact with the ore is replaced by a second wash-water. The silver solution, collected in a circular precipitating vat (10 feet in diameter and 10 feet deep), is treated with sodium sulphide (or calcium polysulphide), unless sodium carbonate was first added to throw down any lead that had gone into solution, and which may have been present in the ore as sulphate. Silver sulphide falls out as a black mud with about 50 per cent. silver, and the solvent will be regenerated: $2Ag_2S_2O_3 + Na_2S_2 = Ag_2S + Na_4S_2O_6$ and $Na_4S_2O_6 + Na_2S_2 = 2Na_2S_2O_3 + 2S$ (or $Ag_2S_2O_3 + CaS_5 = Ag_2S + CaS_2O_3 + S_4$, and in part $CaS_2O_3 + Na_2SO_4 = CaSO_4 + Na_2S_2O_3$). If the sodium cuprous hyposulphite was used as a solvent in addition to the simple sodium hyposulphite, cuprous sulphide will be precipi-

tated with the silver sulphide, and the precipitate will be of lower grade. At some works the silver is precipitated with sodium sulphide, and the liquor, after having been separated from the silver sulphide, is treated with calcium polysulphide, that by the precipitation of calcium sulphate the accumulation of sodium sulphate may be prevented. The precipitated silver (copper) sulphide is filtered, dried, and usually shipped to silver-lead works to be refined; sometimes it is converted into metallic silver at the works. The solution, freed from silver, is used again as solvent. Lixiviation has many advantages over amalgamation. It permits coarser crushing of the ore, the cost of the plant is lower, the power required is nominal, the cost of chemicals is lower than that of quicksilver, less water is necessary, and the extraction is often higher, as silver arsenate and antimoniate are readily soluble, while they are not decomposed in amalgamation. On the other hand, silver and silver sulphide are readily amalgamated; and while they are not dissolved in the Patera process, they are in the Russell process.

Statistics. — The world's production of silver in 1900 was, according to *The Mineral Industry*, Vol. IX, p. 315, in troy ounces: United States, 59,561,797; Canada, 4,446,505; Mexico, 55,804,420; Central America, 1,446,795; Argentina, 383,561; Bolivia, 10,432,685; Chile, 5,772,791; Colombia, 2,800,000; Ecuador, 81,000; Peru, 6,590,955; Austria, 1,272,022; Hungary, 675,750; France, 466,189; Germany, 6,243,326; Greece, 1,294,917; Italy, 1,081,707; Norway, 154,389; Russia, 163,960; Servia, 18,386; Spain, 5,909,418; Sweden, 73,626; Turkey, 65,363; United Kingdom, 191,927; Dutch East Indies, 1,447; Japan, 1,810,375; Australasia, 14,063,244; other countries, 48,226; total, 180,854,781.

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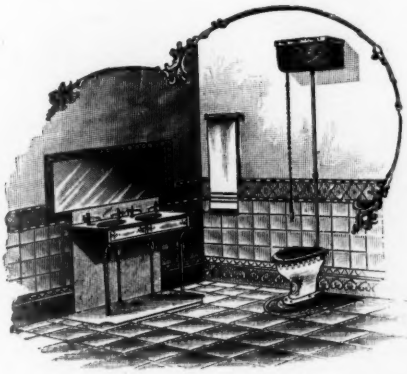

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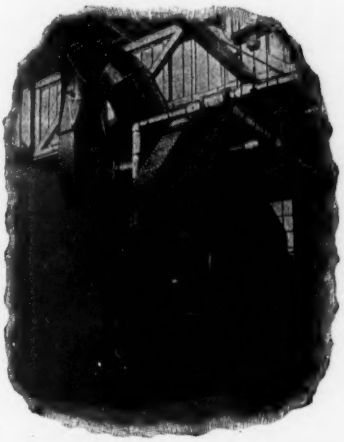

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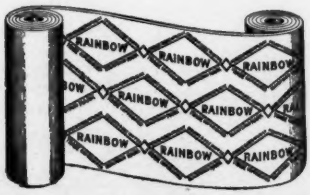

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